Eugene G. Lundquist

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

ORIGINALLY ISSUED
June 1944 as
Memorandum Report

A COMPARISON OF THREE SPINNER-DIFFUSER DESIGNS IN AN NACA D_S COWLING FOR THE PRATT & WHITNEY R-2800 ENGINE

By Louis W. Habel and Peter F. Korycinski

Langley Memorial Aeronautical Laboratory
Langley Field, Va.

NACA

WASHINGTON

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Army Air Forces, Materiel Command

A COMPARISON OF THREE SPINNER-DIFFUSER DESIGNS IN AN NACA D_S COWLING FOR THE PRATT & WHITNEY R-2800 ENGINE

By Louis W. Habel and Peter F. Korycinski

SUMMARY

Tests have been conducted in the LMAL 16-foot high-speed tunnel to determine which of three spinner-diffuser designs on an NACA D_S-type cowling was the most effective in cooling a Pratt & Whitney R-2800 engine installation. The cowling as originally tested had a curved diffuser section and a relatively high inlet-velocity ratio. Two modifications were tested, both of which had straight-wall diffuser sections and lower inlet-velocity ratios than the original installation.

The results of pressure-distribution studies in front of and behind each bank of cylinders are presented for a wide range of propeller-operating conditions. The cooling characteristics of the engine are presented by the National Advisory Committee for Aeronautics method of correlating engine data.

The pressure data indicate that both revised spinner-diffuser arrangements resulted in slightly higher pressures and more uniform pressure distributions at the face of the engine than were obtained with the original arrangement. The results of the cooling correlations indicate that the revised spinner-diffuser arrangements lowered the cylinder-head temperatures from 5° to 15° F below the temperatures of the original design. The base temperatures were practically the same for all three diffusers.

INTRODUCTION

The results of cooling tests of a Pratt & Whitney R-2800 engine installed in an NACA D_S-type cowling were presented in reference 1. A study of these results indicated that better cooling of the engine might be achieved by modifying the spinner-diffuser arrangement. The original cowling installation of reference 1 incorporated a spinner with an abrupt enlargement just short of its major diameter. A small cowling inlet area requiring a high inlet velocity was employed. Between the inlet opening and the face of the engine was located an expanding duct or diffuser having curved-wall sections. Replacement of the diffuser wall sections by straight-wall sections appeared to offer aerodynamic improvements as well as the advantage of structural simplicity. The value of the abrupt enlargement on the spinner was questioned. Moreover, a somewhat lower inlet-velocity ratio seemed desirable. On the basis of these possibilities, two modified spinner-diffuser arrangements were designed for testing in the original cowling. In both modifications the abrupt enlargement of the spinner was abolished and the spinner was faired to a smaller maximum diameter. The maximum diameter of the fairing behind the spinner was reduced to the maximum diameter of the spinner. The diffuser sections for both modified spinner-diffuser arrangements employed straight walls. The difference between the two modifications was only in the angle of the diffuser passage with respect to the thrust axis.

The object of this report is to compare results of tests of the two modified spinner-diffuser arrangements with the results obtained with the original installation in regard to aerodynamic and engine-cooling characteristics.

Engine-cooling tests were made in which complete pressure-distribution data were obtained for a wide range of propeller-operating conditions and various cowling-flap settings. The engine was operated over a range of power conditions up to rated power. Test results are presented only for zero angle of attack.

DESCRIPTION OF MODEL AND APPARATUS

The model on which the three spinner-diffuser arrangements were tested is shown mounted in the 16-foot high-speed-tunnel test section in figure 1. A complete description of the power plant and propeller is given in reference 1. The general shape and coordinates of the cowling and the original spinner and diffuser are given in figure 2. The original spinner was designed with an abrupt increase in diameter immediately ahead of the cowling entrance. The intended purpose of this "hump" was to thin out the boundary layer and to obtain a favorable pressure gradient at the diffuser entrance. The original diffuser walls were curved and were apparently designed to direct the cooling air flow toward the cylinder barrels.

The modification A spinner-diffuser arrangement was designed to provide a lower inlet-velocity ratio than that obtained with the original installation. The lower inlet-velocity ratio offered the possibility of less diffuser loss, increased pressures, and better pressure distribution at the engine cylinders.

The most convenient method of increasing the cowling inlet area was to reduce the maximum diameter of the rotating spinner, changing only the rear portion where the diameter of the spinner had been abruptly increased to form the hump. The diameter of the fairing behind the spinner was also reduced and was made conical with the maximum diameter equalling that of the rotating spinner. Both walls of the diffuser were straight.

The modification B spinner-diffuser arrangement was similar to the modification A design. The main difference was that the fairing behind the rotating spinner was cylindrical with the diameter matching the maximum diameter of the rotating spinner. The modification A arrangement directed the flow of cooling air toward the central portion of the cylinder, whereas the modification B design favored the upper portion of the cylinder. Otherwise the two modifications were identical. Figure 3 shows the spinner-diffuser configurations for the three arrangements described.

The normal carburetor-air inlet was blocked off for all tests so that the quantity of charge air could be measured through an external duct system in which a calibrated venturi had been installed. The blocked-off carburetor duct and a portion of the external charge-air duct which is aft of the venturi may be seen in figure 1.

The inlet-velocity ratios were obtained by means of four shielded total-pressure rakes and surface static orifices in the diffuser entrance. The location of these tubes is shown in figure 4 for the original diffuser and in figure 5 for both modified diffusers. The location of pressure tubes on the individual engine cylinders is presented in figure 6.

Three thermocouples were installed on each of the 18 engine cylinders. One was embedded approximately 1/16 inch deep in the cylinder head at the rear spark-plug boss on the center line between the two spark plugs approximately 3/4 inch behind the center of the rear spark plug. Another was embedded approximately 3/16 inch deep in the flange at the rear of the cylinder base 3/4 inch from the edge of the flange slightly to the left of the center line of the cylinder as viewed from the rear of the engine while looking at one of the top cylinders. The third was the spark-plug gasket type of thermocouple and was installed between the rear spark plug and the cylinder head. The temperatures were recorded on a self-balancing potentiometer.

The cowling flaps were operated manually. In their neutral or "closed" position, the cowling-flap gap was 2.5 inches. In the maximum or "full open" position of the cowling flaps, the gap was 7.2 inches.

SYMBOLS

p/q_c	pressure coefficient
p	pressure referenced to free-stream static pressure, pounds per square foot
q_c	indicated dynamic pressure, pounds per square foot $\left(F_c \rho V^2/2\right)$
ρ	mass density of air, slugs per cubic foot
V	velocity, feet per second

F_c compressibility factor for air $\left(1 + \frac{M^2}{4} + \frac{M^4}{40} + \ldots\right)$

M Mach number, the ratio of tunnel airspeed to acoustic velocity in air

V/nD propeller advance ratio

n propeller rotational speed, revolutions per second

D propeller diameter, feet

C_P power coefficient $(P/\rho n^3 D^5)$

P power, foot-pounds per second

σ relative density of air $(\rho/0.002378)$

σ_2 relative density of air at the stagnation point (relative density of the cooling air)

Δp cooling-air pressure drop, inches of water

α_T angle of attack of thrust axis, degrees

W_e weight flow of charge air, pounds per hour or pounds per second

T cylinder-head or cylinder-base temperature (average indication of 18 thermocouples), $^{\circ}F$

T_a cooling-air temperature (stagnation-air temperature in front of engine), $^{\circ}F$

$T_{g_{80}}$ reference mean effective gas temperature (for an 80° F charge-air temperature), $^{\circ}F$

T_h cylinder-head temperature (average of 18 thermocouples embedded in the rear spark-plug boss), $^{\circ}F$

T_b cylinder-base temperature (average of 18 thermocouples embedded in the cylinder flange), $^{\circ}F$

T_{sp} cylinder-head temperature (average of 18 spark-plug gasket thermocouples), $^{\circ}F$

m (y/z)

y and z exponents associated with W_e and $\sigma_2 \Delta p$, respectively

TESTS

Tests were made to obtain radial and circumferential pressure-distribution data as well as diffuser pressures for a wide range of propeller-operating conditions and tunnel speeds and with several cowling-flap positions ranging from closed to full open. Another series of tests was made to determine the variation in pressure in front of and behind the engine with change of V/nD for several power coefficients and cowling-flap positions. The propeller advance ratios ranged from approximately 0.8 to 2.8; the values of power coefficients used in these tests were 0.1, 0.2, and 0.3.

The tests to establish the engine-cooling-correlation curves for each spinner-diffuser design followed the usual NACA cooling-correlation test procedure. In particular, the engine power ranged from 400 to 1630 brake horsepower. The engine was operated almost entirely at 2120 revolutions per minute for all but the 1600-brake-horsepower runs which were run at 2400 revolutions per minute. The fuel-air ratios were varied from slightly more than 0.05 to slightly in excess of 0.11 for tests of the original and modification A spinner-diffuser arrangements. Variable fuel-air-ratio data for the modification B spinner-diffuser arrangement were not obtained.

RESULTS AND DISCUSSION

Aerodynamics of Cooling-Air Flow

Radial pressure distribution.- The radial pressures at zero angle of attack at the various stations through the three variations of the cowling tested are presented in terms of indicated dynamic pressure in figure 7. The data used to illustrate these radial pressures are for a V/nD of 1.7, C_p of 0.16, and a true airspeed of

260 miles per hour; the cowling-flap gaps were set at 2.5 and 7.2 inches. The results at this test condition are typical of the results obtained at the other test conditions. The points plotted represent pressures obtained by averaging all pressure-tube readings at given distances from the horizontal center line of the engine.

The fact that higher pressure recoveries were found at station 1 in the cowling diffuser entrance when the cowling flaps were open than were found when the flaps were closed has been discussed in reference 1 and was apparently due to stalling of the propeller-blade sections in front of the cowling entrance at the low-inlet-velocity flaps-closed condition. The pressures at this station were slightly higher for the original spinner-diffuser arrangements than for either modified arrangement, probably because of the higher inlet velocity.

The inlet-velocity ratios are shown in the following table for each of the three spinner-diffuser designs at the two extreme positions of the cowling flaps.

INLET-VELOCITY RATIOS

Spinner-diffuser arrangement	2.5-inch cowling-flap gap (minimum opening)	7.2-inch cowling-flap gap (maximum opening)
Original	0.68	0.89
Modification A	.58	.77
Modification B	.59	.78

At the front face of the front row of cylinders, station 2, only small differences were noted between the results for the modified spinner-diffuser arrangements, both of which presented higher pressures than did the original installation at this station. It should be noted that the pressures at station 2 were improved in spite of the loss at station 1 suffered by the modified arrangements as a result of propeller cuff stalling. Therefore, the gains due to the modified spinner-diffuser designs are greater than indicated by simply comparing pressures at station 2. These gains were largest at the top of the cylinder heads and at the cylinder barrels. Of interest is the fact that the modified spinner-diffuser arrangements allowed higher pressures at the cylinder barrels than did the original design in which the air flow was directed toward the cylinder barrels, as is shown in figure 3. The low pressure at the cylinder barrels presented by the original spinner-diffuser arrangement is evidently due to separation in the diffuser.

Even though the radial pressure distribution was somewhat improved by the modified spinner-diffuser designs, the pressure distribution is still not as good as is usually obtained with an NACA "C" cowling which presents a more uniform radial pressure distribution in front of the engine. The poor radial pressure distribution is apparently an inherent characteristic of the "D_S" type of cowling.

At station 3, the original spinner-diffuser arrangement shows a slight advantage over the two modifications. The pressure drop across the front bank of cylinders, if measured by the central total-head and central static tubes, would credit the original design with the highest value. However, the integrated average pressure drop would be the highest for the two modified designs.

For all diffusers the radial pressure distribution obtained at the front face of the rear row of cylinders, station 4, was uniform. Both modified arrangements presented higher pressures at station 4 than did the original arrangement.

Fairly uniform static-pressure distribution occurred at station 5. However, the pressure drop across the rear bank of cylinders was decidedly higher with either modification.

Circumferential pressure distribution.- The circumferential pressure distribution at the front and rear of each bank of cylinders is presented in figures 8 through 11. To illustrate the circumferential pressures, the data were used from the same test conditions as were used to illustrate the radial pressures. The figures 8 through 11 indicate that the modifications had only slight effects on the circumferential pressure pattern.

With the original spinner-diffuser arrangement, as discussed in reference 1, low pressures were experienced on cylinders 2 and 18. This was attributed to either the air flow breaking down in the diffuser section over the indentations in the diffuser, which were to compensate for the space occupied by the two distributors, the magneto and the propeller governor, or to the air flow breaking down at the cowling entrance due to the blocked-off carburetor duct shown in figure 1. The pressures on these two cylinders appear to have been improved considerably, probably because of the lower inlet-velocity ratios of the modified spinner-diffuser designs. Increasing the pressures on cylinders 2 and 18 brought the pressures on these two cylinders up nearer the average of the other cylinders in the front bank. This increase in pressure resulted in a more uniform circumferential pressure distribution than was obtained with the original installation.

On the rear bank of cylinders, the pressure distribution remained irregular with only slight differences occurring in the pattern for the various diffusers.

Pressure available.- The change in average pressure coefficient at the face of the engine with variation of propeller advance ratio is presented in figures 12 and 13 for all three spinner-diffuser arrangements at power coefficients of 0.1, 0.2, and 0.3 for the two extreme cowling-flap positions. Data were also obtained with a 4-inch cowling-flap gap but is not presented because in all cases it fell between the curves obtained with the cowling flaps in the two extreme positions. The average pressures shown in these figures include only the pressures near the centers of the heads and barrels and thus do not show effects at the top of the heads where the largest gains occurred with the modified spinner-diffuser arrangements.

With a cowling-flap gap of 2.5 inches (fig. 12) at the cylinder heads, the pressure coefficients were practically the same for all three spinner-diffuser arrangements with the exception of those obtained with a power coefficient of 0.1, at the lower values of propeller advance ratio, where the revised spinner-diffuser arrangements had a definite advantage over the original installation. At the cylinder bases the pressures were highest for the modification A spinner-diffuser arrangement for all values of power coefficient tested. The original installation and the modification B spinner-diffuser arrangement gave practically the same pressures for corresponding values of V/nD.

With a cowling-flap gap of 7.2 inches (fig. 13) the modification B spinner-diffuser arrangement gave higher pressure coefficients for all values of power coefficient tested than did the modification A spinner-diffuser arrangement. The original installation presented an almost constant pressure coefficient which is slightly higher than the modified installations above values of V/nD of 1.24, 1.78, and 2.20 for power coefficients of 0.1, 0.2, and 0.3, respectively. At the cylinder bases, the pressure coefficients are again highest for the modification A spinner-diffuser arrangement. The pressure coefficients for the original installation and the modification B spinner-diffuser arrangement are practically the same for values of propeller advance ratio above approximately 1.8 for power coefficients of 0.2 and 0.3. For these power coefficients, at values of propeller advance ratio below 1.8, the modification B installation had an advantage over the original configuration.

The variations of pressure coefficient at the rear of the engine with propeller advance ratio are presented in figure 14 for the full-closed cowling-flap position and in figure 15 for the full-open cowling-flap position. The average static pressure at the rear of the engine is dependent principally on the flap setting for a given value of V/nD. It is considered that the changes in pressure coefficient shown between the various spinner-diffuser arrangements may be accounted for by unavoidable inaccuracy in cowling-flap setting.

Engine temperature patterns.- Typical engine temperature patterns are presented for all three spinner-diffuser arrangements at the two extreme positions of cowling flaps in figure 16. There were no radical changes in temperature pattern caused by either of the modified cowlings. Cylinder 14 continued to run hotter than any of the other cylinders. An examination of the circumferential pressure data indicates that cylinder 14 was receiving a fair share of the cooling air and, therefore, the high temperature obtained must be attributed to other causes.

Engine-Cooling Correlation

The engine-cooling-correlation curves for the original diffuser have been presented in an earlier report (reference 1). Complete engine-cooling-correlation data are presented in this report for the two revised spinner-diffuser arrangements as well as for the original installation (tables I, II, and III).

The pressure orifice locations used to measure the pressure drop across the engine for the cooling correlations are shown in figure 6. The pressure drop across the cylinder heads was measured as the difference between the total pressure registered by tube A, located at the baffle entrance of the front bank of cylinders, and the pressure registered by tube B, a closed-end static tube at the top of the cylinder-head baffle between the exhaust port and the blast tube of each cylinder in the rear bank. The cooling-air pressure drop across the cylinder barrels was measured as the difference between the total pressure indicated by tube C at the front-barrel baffle entrance and the static pressure indicated by tube D, an open-end tube in the curl of the baffle behind the rear bank barrel. The values of cooling-air pressure drop used in the correlation are circumferential averages over the entire engine.

A comparison of the engine-cooling-correlation curves for the three spinner-diffuser arrangements is presented in figure 17. The cooling-correlation equations for each of the spinner-diffuser designs are given in table IV. A study of figure 17 shows that the differences between the original and modification B cowling installations are very small. The modification A spinner-diffuser arrangement, however, shows an advantage for head temperatures and slight disadvantage for the base temperatures. The maximum cylinder-temperature difference between the installations, for the bases, is of the order of 2° to 4° F and thereby practically within the limits of experimental accuracy. For the heads, the maximum temperature reduction for the modification A spinner-diffuser design amounts to approximately 15° F.

The NACA engine-cooling correlation embodies the principles set forth in references 2, 3, and 4; these principles show that the ratio of the cooling-temperature differential to the heating-temperature differential is a function of a relationship between the internal flow of the heating fluid and the external flow of the cooling fluid. This relationship is expressed by

$$\frac{T_h - T_a}{T_g - T_h} = c_1 \frac{W_e{}^y}{(\sigma_2 \Delta p)^z}$$

When a single total-head tube and a single static tube are used to measure the pressure drop across a cylinder, the resulting correlation curve may seem to have been affected by the location of the total-pressure tube; in other words, one diffuser which directs the air flow squarely upon the reference total-head tube may be credited with a greater pressure drop than another diffuser which does not influence the reference total-head tube directly. (See fig. 3.) Pressure drop alone is not necessarily an indication that one diffuser is more effective than another in cooling the engine; actually it is the engine temperature corresponding to a given pressure drop which is the true measure of the engine-cooling effectiveness of a given cowling installation. The engine-cooling-correlation curves presented in this report apply only to the particular installation of pressure tubes and thermocouples used in these tests. If more general results were to be obtained, a more complete installation of pressure tubes and thermocouples would be needed for each cylinder so that true average pressure drops across the cylinder and true average cylinder temperature could be obtained. Inasmuch as the engine instrumentation was the same in all cases, the correlation curves may be used to show the relative effectiveness of the various spinner-diffuser arrangements in cooling the engine for a given indicated cooling-air pressure drop.

The variation of mean effective gas temperature with fuel-air ratio for the original and modification A spinner-diffuser arrangements is shown in figure 18. The gas-temperature data for modification B were not measured, but the faired curves in figure 18 may be used with all three correlations. The mean effective gas temperature is referenced to 80° carburetor air.

The engine-temperature relationships for the three spinner-diffuser arrangements are shown in figure 19.

The plotted points represent temperatures obtained for all engine-cooling-correlation tests. Plots of hottest head embedded temperature against average head embedded temperature and hottest spark-plug gasket temperature versus average spark-plug gasket temperature show that no definite relationship existed between the different spinner-diffuser designs. The plot of average spark-plug gasket against average head embedded temperatures shows the curve for the original installation approximately 15° higher than for the other installations. Little variation is found in the plot of hottest base embedded temperature versus average base embedded temperature.

Figure 20 shows the computed average cylinder temperatures that would be obtained over a range of airspeeds for two assumed engine-operating conditions. This figure was prepared on the basis of the cooling-correlation results. A cruise condition with 1100 brake horsepower, 2120 revolutions per minute, and $F/A = 0.08$, and a high-speed condition with 1600 brake horsepower, 2600 revolutions per minute, and $F/A = 0.11$ were assumed. The weight of charge air required in the calculations was obtained from the present test data. The mean effective gas temperature was computed by equation (2) of reference 1 using figure 18 to obtain $T_{g_{80}}$.

It will be noted that the average head temperatures are approximately 5° F lower with the modification B diffuser and approximately 15° F lower with the modification A diffuser than was obtained with the original installation. The base temperatures were relatively unaffected by the modifications.

If 450° F is considered as the maximum permissible cylinder-head temperature for continuous operation, the average cylinder-head temperature would be approximately 410° F. For the cruise condition, an airspeed of 240 miles per hour is needed to cool the cylinder heads with the original spinner-diffuser arrangement. To cool adequately with the modification A spinner-diffuser arrangement, an airspeed of 216 miles per hour is required. For the high-speed condition, an airspeed of 224 miles per hour is needed to cool the cylinder heads with the original installation while with the modification A configuration the same cooling is accomplished with an airspeed of 196 miles per hour.

The maximum permissible cylinder-base temperature is taken as 335° F. Since the temperature difference between the individual cylinder bases is relatively small, a maximum average cylinder-base temperature of 320° F may be used. For the cruise condition, the cylinder bases will cool adequately for all of the spinner-diffuser arrangements at any airspeed greater than 165 miles per hour. For the high-speed condition, the cylinder bases will be adequately cooled above an airspeed of 205 miles per hour if the original installation or the modification B installation is used. If the modification A spinner-diffuser arrangement is used, the same airspeed is needed to cool the cylinder bases as was required to cool the cylinder heads, 196 miles per hour.

CONCLUSIONS

1. Both modified spinner-diffuser arrangements produced a larger average pressure drop available to cool the engine than was obtainable with the original installation.

2. The engine-cooling-correlation curves indicate that the modification A spinner-diffuser arrangement was the most effective in cooling the engine and resulted in a reduction of the average cylinder-head temperature of approximately 15° F for a given index pressure drop as compared with the original installation.

3. For the cruise condition, the modification A spinner-diffuser arrangement will provide adequate cooling of the Pratt & Whitney R-2800 engine at an airspeed which is approximately 20 miles per hour lower than is needed with the original installation. Adequate cooling at the high-speed condition can be achieved at a 30-mile-per-hour lower airspeed by using the modification A spinner-diffuser arrangement rather than the original installation.

Langley Memorial Aeronautical Laboratory
National Advisory Committee for Aeronautics
Langley Field, Va., June 17, 1944

REFERENCES

1. Corson, Blake W., Jr., and McLellan, Charles H.: Cooling Characteristics of a Pratt & Whitney R-2800 Engine Installed in an NACA Short-Nose High-Inlet-Velocity Cowling. NACA ACR No. L4F06, 1944.

2. Pinkel, Benjamin: Heat-Transfer Processes in Air-Cooled Engine Cylinders. NACA Rep. No. 612, 1938.

3. Schey, Oscar W., Pinkel, Benjamin, and Ellerbrock, Herman H., Jr.: Correction of Temperatures of Air-Cooled Engine Cylinders for Variation in Engine and Cooling Conditions. NACA Rep. No. 645, 1938.

4. Pinkel, Benjamin, and Ellerbrock, Herman H., Jr.: Correlation of Cooling Data from an Air-Cooled Cylinder and Several Multicylinder Engines. NACA Rep. No. 683, 1940.

TABLE 1.- ENGINE-COOLING CORRELATION DATA FOR ORIGINAL

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Test and run	bhp	Engine speed (rpm)	Charge-air flow (lb/hr)	Fuel flow (lb/hr)	Fuel-air ratio	Carburetor air temperature (°F)	T_a (°F)	ΔT_g (°F)	T_{g80} heads (°F)	T_{gh} (°F)	T_h (°F)	$\frac{T_h - T_a}{T_{gh} - T_h}$	$\sigma_2 \Delta p_h$	$\frac{W_e^{1.76}}{\sigma_2 \Delta p_h}$	T_{g80} bases (°F)	T_{gb} (°F)	T_b (°F)	$\frac{T_b - T_a}{T_{gb} - T_b}$	$\sigma_2 \Delta p_b$	$\frac{W_e^{1.67}}{\sigma_2 \Delta p_b}$
Test with Constant Fuel-Air Ratio																				
240- 1	1100	2120	8040	640	0.0796	68	96	69	1154	1223	331	0.264	43.0	0.096	607	671	244	0.347	31.6	0.121
240- 2	1100	2120	7973	646	.0810	70	97	71	1141	1212	339	.277	36.9	.110	596	667	248	.359	27.1	.139
240- 3	1100	2120	7987	640	.0802	71	99	72	1148	1220	353	.293	31.1	.131	599	671	257	.381	22.7	.167
240- 4	1100	2120	7937	630	.0794	73	100	73	1154	1227	367	.310	25.6	.157	603	676	263	.395	18.7	.200
240- 5	1100	2120	7803	630	.0808	73	101	73	1143	1216	385	.342	19.3	.203	596	669	273	.434	14.1	.259
240- 6	1100	2120	7770	613	.0788	77	100	77	1160	1237	408	.372	13.1	.296	615	682	287	.473	10.4	.348
240- 7	1100	2120	7750	613	.0791	78	97	77	1157	1234	437	.427	9.7	.398	604	681	305	.553	7.2	.500
240- 8	1100	2120	7790	615	.0790	81	102	80	1158	1238	367	.304	30.8	.126	604	684	263	.382	22.8	.159
240- 9	1100	2120	7677	619	.0806	80	99	79	1145	1224	403	.370	14.9	.254	503	676	286	.479	11.7	.303
240-10	1100	2120	7830	623	.0795	80	102	79	1154	1233	362	.299	31.1	.126	602	681	263	.385	24.2	.151
240-12	1100	2120	7855	613	.0780	71	91	72	1167	1239	350	.291	31.4	.126	609	681	253	.378	23.3	.158
240-13	1100	2120	7743	592	.0765	70	91	71	1180	1251	374	.323	19.5	.197	615	686	268	.423	15.4	.234
240-14	1100	2120	7695	592	.0769	67	92	69	1176	1245	397	.360	14.8	.257	614	683	276	.452	10.8	.329
240-15	1100	2120	7578	565	.0746	70	87	71	1198	1268	421	.394	9.5	.390	624	695	294	.516	7.5	.461
240-16	1100	2120	7708	603	.0782	67	91	69	1165	1234	396	.364	14.7	.260	608	677	277	.465	10.7	.334
241- 1	600	2120	4647	347	.0746	70	84	71	1198	1268	338	.273	13.5	.116	624	695	247	.364	10.1	.151
241- 2	800	2120	5793	454	.0784	69	85	70	1163	1233	356	.309	14.5	.159	607	677	256	.406	10.8	.205
241- 3	990	2120	7013	551	.0785	69	87	70	1162	1232	383	.349	14.2	.228	607	677	270	.450	10.9	.279
241- 4	1200	2120	8300	644	.0775	68	88	69	1171	1240	404	.378	14.4	.303	611	680	280	.480	11.0	.367
241- 5	600	2120	4613	355	.0769	70	86	71	1176	1247	337	.276	14.2	.109	614	685	248	.381	10.6	.142
Tests with Variable Fuel-Air Ratio																				
242- 1	800	2120	5820	461	0.0801	79	97	78	1142	1220	362	0.309	14.7	0.159	586	664	260	0.405	11.1	0.201
242- 2	800	2120	5730	424	.0740	78	98	77	1183	1260	368	.303	15.0	.151	610	687	263	.389	12.6	.173
242- 3	800	2120	5780	394	.0681	80	99	79	1191	1270	374	.307	14.8	.155	601	680	266	.403	11.1	.199
242- 4	800	2120	5840	382	.0655	80	98	79	1186	1265	373	.308	14.9	.157	593	672	264	.408	11.0	.205
242- 5	800	2120	6133	373	.0608	80	98	79	1131	1210	366	.318	14.8	.172	577	656	262	.416	11.1	.220
242- 6	800	2120	6740	385	.0571	81	99	80	1021	1101	350	.334	15.0	.201	538	618	256	.432	11.2	.254
242- 7	800	2120	5770	432	.0748	81	98	80	1180	1260	371	.307	14.9	.154	606	686	266	.401	11.2	.196
242- 8	800	2120	5790	396	.0683	82	99	81	1194	1275	376	.308	14.8	.156	607	688	268	.403	11.1	.199
242- 9	800	2120	7370	390	.0530	78	99	77	926	1003	334	.352	14.9	.237	507	584	250	.452	11.1	.298
242-10	800	2120	6187	374	.0603	77	96	77	1108	1185	359	.318	15.1	.172	570	646	257	.415	11.3	.219
242-11	800	2120	5950	377	.0633	75	94	75	1161	1236	364	.309	15.2	.159	591	666	259	.407	11.4	.204
242-12	800	2120	5727	405	.0707	72	92	73	1182	1255	364	.305	15.1	.152	607	680	260	.400	11.3	.192
244- 1	1400	2120	10533	1139	.1081	56	79	60	880	940	337	.429	15.1	.438	518	578	252	.529	11.7	.513
244- 2	1400	2120	10260	1038	.1011	59	81	62	913	975	350	.430	14.2	.444	546	608	262	.525	11.4	.504
244- 3	1400	2120	9853	890	.0904	60	82	63	1048	1111	382	.412	14.9	.395	584	647	274	.515	11.4	.470
244- 4	1100	2120	7697	608	.0791	61	81	64	1136	1200	377	.359	15.1	.252	610	674	267	.457	11.6	.307
244- 5	1100	1749	7608	605	.0795	61	81	39	1116	1155	362	.355	15.3	.244	587	626	250	.451	11.8	.298
244- 6	1040	2501	7688	606	.0788	61	81	95	1171	1266	397	.364	14.5	.263	657	752	293	.462	11.1	.320
244- 7	1630	2400	13117	1490	.1136	61	83	86	818	904	356	.499	13.9	.701	516	602	276	.591	11.2	.773

TABLE II

ENGINE-COOLING CORRELATION DATA FOR MODIFICATION-A

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Test and run	bhp	Engine speed (rpm)	Charge-air flow (lb/hr)	Fuel flow (lb/hr)	Fuel air ratio	Carburetor air temperature (°F)	T_a (°F)	ΔT_g (°F)	$\Delta T_{g_{80}}$ heads (°F)	T_{g_h} (°F)	T_h (°F)	$\frac{T_h - T_a}{T_{g_h} - T_h}$	$\sigma_2 \Delta p_h$	$\frac{W_e^{1.76}}{\sigma_2 \Delta p_h}$	$T_{g_{80}}$ bases (°F)	T_{g_b} (°F)	T_b (°F)	$\frac{T_b - T_a}{T_{g_b} - T_b}$	$\sigma_2 \Delta p_b$	$\frac{W_e^{1.65}}{\sigma_2 \Delta p_b}$
Tests with Constant Fuel-Air Ratio																				
250-1	1100	2120	7930	630	0.0796	48	74	53	1153	1206	306	0.258	43.5	0.092	601	654	223	0.346	37.2	0.099
250-2	1100	2120	7880	633	.0805	49	75	54	1144	1198	310	.265	38.7	.102	599	653	227	.357	37.4	.097
250-3	1100	2120	7830	626	.0802	50	75	55	1147	1202	317	.273	33.1	.119	600	655	232	.371	26.3	.137
250-4	1100	2120	7780	620	.0799	50	76	55	1151	1206	329	.288	27.2	.143	600	655	239	.392	21.3	.167
250-5	1100	2120	7740	618	.0798	52	77	57	1152	1209	344	.309	21.9	.175	600	657	248	.418	16.9	.209
250-6	1100	2120	7810	618	.0793	53	80	57	1155	1212	322	.272	33.7	.116	601	258	236	.370	26.6	.135
250-7	1100	2120	7680	618	.0804	53	76	57	1146	1203	363	.342	15.0	.253	599	656	260	.465	12.0	.291
250-8	1100	2120	7630	612	.0802	53	73	57	1147	1204	399	.405	9.2	.407	600	657	282	.557	7.6	.454
251-1	1100	2120	7680	587	.0764	55	74	59	1173	1232	425	.435	7.1	.534	604	663	293	.592	5.9	.592
251-2	400	2120	3600	253	.0703	63	81	65	1194	1259	291	.217	15.5	.065	606	671	227	.329	12.4	.081
251-3	500	2120	4160	321	.0772	63	81	65	1169	1234	306	.242	15.1	.085	603	668	232	.346	12.1	.105
251-4	700	2120	5240	397	.0757	62	82	65	1177	1242	332	.275	15.1	.128	605	670	245	.384	12.2	.152
251-5	900	2120	6490	487	.0750	63	84	65	1181	1246	350	.297	15.0	.188	605	670	256	.415	12.1	.219
251-6	1100	2120	7790	614	.0788	64	87	66	1158	1224	376	.341	14.8	.263	602	668	270	.460	12.2	.293
251-7	1200	2120	8390	657	.0783	63	88	65	1162	1227	387	.356	14.9	.298	602	667	274	.473	12.0	.337
Tests with Variable Fuel-Air Ratio																				
251- 8	800	2120	5870	425	0.0724	64	86	66	1203	1269	357	0.297	15.1	0.157	602	668	257	0.416	12.2	0.184
251- 9	800	2120	5840	404	.0691	64	86	66	1192	1258	353	.295	15.1	.155	600	666	256	.415	12.2	.182
251-10	800	2120	6070	381	.0627	64	86	66	1160	1226	351	.303	14.8	.169	592	658	256	.423	12.0	.197
251-11	800	2120	5890	391	.0663	64	86	66	1196	1262	356	.298	15.0	.159	599	665	257	.419	12.0	.188
251-12	800	2120	6510	378	.0581	64	84	66	1066	1132	335	.315	14.9	.190	557	623	249	.441	11.8	.225
251-13	800	2120	7000	384	.0548	63	86	65	983	1048	323	.327	15.0	.215	533	598	245	.451	12.1	.247
251-14	800	2120	7160	387	.0541	63	83	65	945	1010	314	.332	14.9	.225	522	587	241	.456	12.1	.257
251-15	1400	2120	10390	1083	.1042	61	84	64	915	979	341	.403	15.1	.427	506	570	255	.542	12.1	.471
251-16	1400	2120	10060	972	.0967	61	83	64	995	1059	361	.398	15.1	.405	534	598	262	.532	12.2	.447
251-17	1400	2120	9690	840	.0867	60	84	63	1115	1178	391	.390	15.1	.378	577	640	275	.523	12.2	.419
251-18	1600	2400	12660	1409	.1113	59	83	85	867	952	354	.453	14.9	.614	515	600	275	.590	12.3	.647

TABLE III

ENGINE COOLING CORRELATION DATA FOR MODIFICATION-B

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Test and run	bhp	Engine speed (rpm)	Charge-air flow (lb/hr)	Fuel flow (lb/hr)	Fuel-air ratio	Carburetor air temperature (°F)	T_a (°F)	ΔT_g (°F)	$T_{g_{80}}$ heads (°F)	T_{g_h} (°F)	T_h (°F)	$\frac{T_h - T_a}{T_{g_h} - T_h}$	$\sigma_2 \Delta p_h$	$\frac{W_e^{1.76}}{\sigma_2 \Delta p_h}$	$T_{g_{80}}$ bases (°F)	T_{g_b} (°F)	T_b (°F)	$\frac{T_b - T_a}{T_{g_b} - T_b}$	$\sigma_2 \Delta p_b$	$\frac{W_e^{1.63}}{\sigma_2 \Delta p_b}$
Test with Constant Fuel-Air Ratio																				
354-1	1100	2120	7750	624	0.0805	57	79	61	1142	1203	310	0.259	46.3	0.083	598	659	226	0.340	33.5	0.104
354-2	1100	2120	7670	612	.0798	57	76	61	1152	1213	324	.279	34.4	.110	600	661	232	.364	25.3	.136
354-3	1100	2120	7620	610	.0801	56	74	60	1149	1209	342	.309	24.5	.153	599	659	242	.398	18.2	.187
354-4	1100	2120	7570	606	.0801	57	73	61	1142	1203	365	.348	16.3	.226	598	659	256	.454	12.3	.273
354-5	1100	2120	7545	604	.0801	58	71	62	1146	1208	381	.375	13.0	.282	598	660	264	.488	9.7	.344
356-1	1100	2120	7750	624	.0805	63	84	66	1142	1208	334	.286	35.5	.108	598	664	238	.361	26.0	.134
356-2	1100	2120	7660	608	.0794	63	86	66	1152	1218	368	.332	19.7	.192	600	666	255	.409	13.6	.254
356-3	1100	2120	7650	614	.0803	65	87	67	1146	1213	381	.353	15.8	.239	598	665	264	.444	11.1	.308
356-4	1100	2120	7620	615	.0807	66	87	68	1136	1204	400	.389	11.7	.320	597	665	276	.486	8.5	.400
357-1	1100	2120	7605	609	.0801	60	81	63	1150	1213	364	.333	19.7	.190	600	663	253	.419	13.5	.251
357-2	1100	2120	7560	606	.0802	62	82	65	1144	1209	377	.355	15.6	.237	598	663	262	.449	11.0	.308
357-3	400	2120	3475	261	.0751	67	79	69	1180	1249	294	.225	16.4	.058	606	675	224	.322	12.0	.079
357-4	500	2120	4055	303	.0747	66	79	68	1181	1249	306	.241	16.5	.075	606	674	228	.336	12.0	.101
357-5	700	2120	5180	398	.0768	64	79	66	1175	1241	330	.276	16.1	.118	605	671	238	.367	12.0	.151
357-6	900	2120	6370	504	.0791	63	79	66	1152	1218	350	.312	16.0	.171	600	666	248	.404	11.9	.213
357-7	1100	2120	7595	602	.0793	63	81	66	1154	1220	374	.346	16.0	.232	600	666	260	.441	11.8	.286
357-8	1200	2120	8200	655	.0799	62	82	65	1146	1211	386	.368	15.8	.269	598	663	266	.466	11.8	.324

TABLE IV.- ENGINE-COOLING-CORRELATION EQUATIONS

Spinner-diffuser arrangement	Heads	Bases
Original	$\frac{T_h - T_a}{T_g - T_h} = 0.561\left(\frac{W_e^{1.76}}{\sigma_2 \Delta p}\right)^{0.321}$	$\frac{T_b - T_a}{T_g - T_b} = 0.643\left(\frac{W_e^{1.67}}{\sigma_2 \Delta p}\right)^{0.289}$
Modification A	$\frac{T_h - T_a}{T_g - T_h} = 0.523\left(\frac{W_e^{1.76}}{\sigma_2 \Delta p}\right)^{0.310}$	$\frac{T_b - T_a}{T_g - T_b} = 0.357\left(\frac{W_e^{1.65}}{\sigma_2 \Delta p}\right)^{0.290}$
Modification B	$\frac{T_h - T_a}{T_g - T_h} = 0.543\left(\frac{W_e^{1.76}}{\sigma_2 \Delta p}\right)^{0.303}$	$\frac{T_b - T_a}{T_g - T_b} = 0.660\left(\frac{W_e^{1.63}}{\sigma_2 \Delta p}\right)^{0.300}$

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

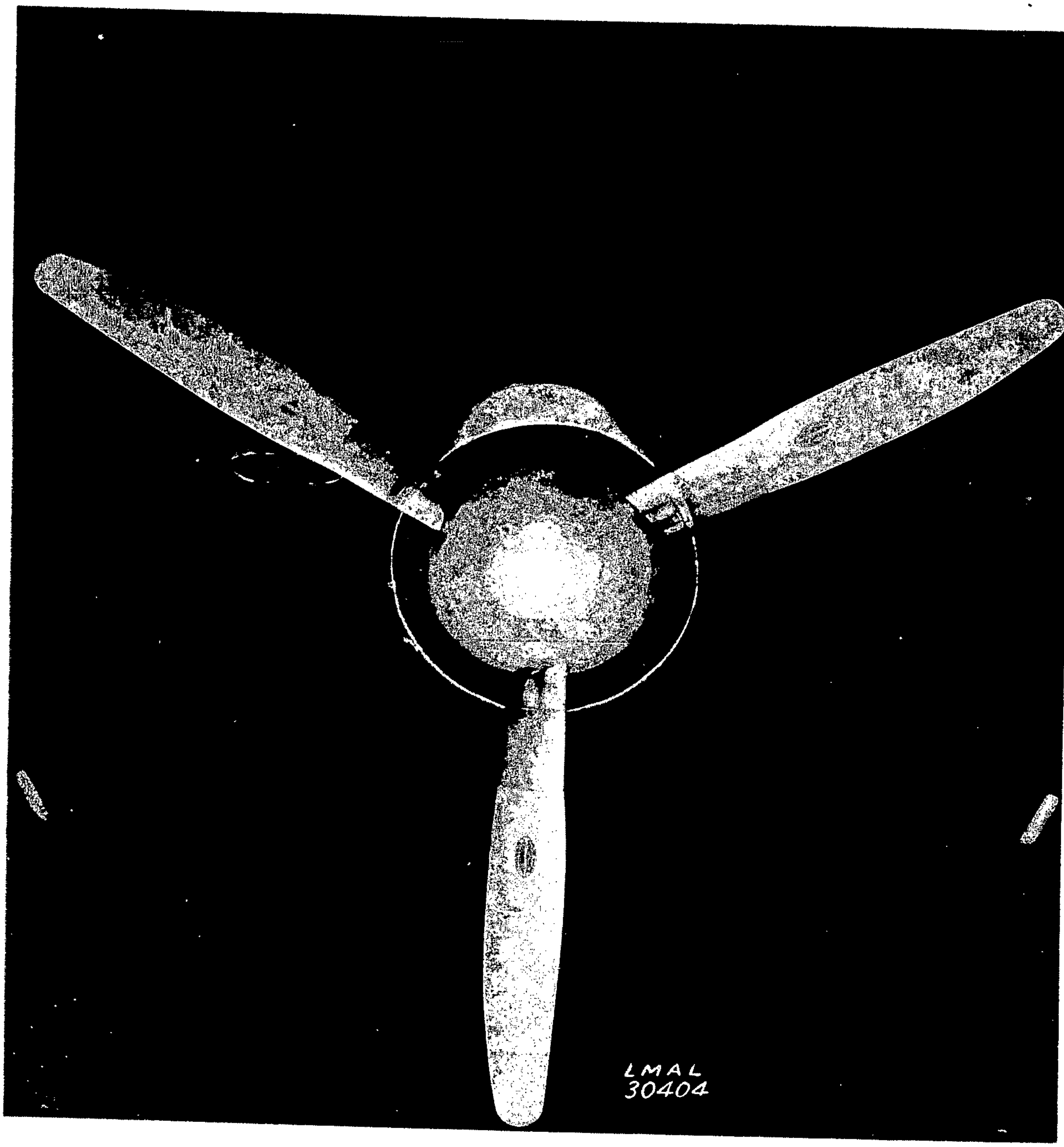
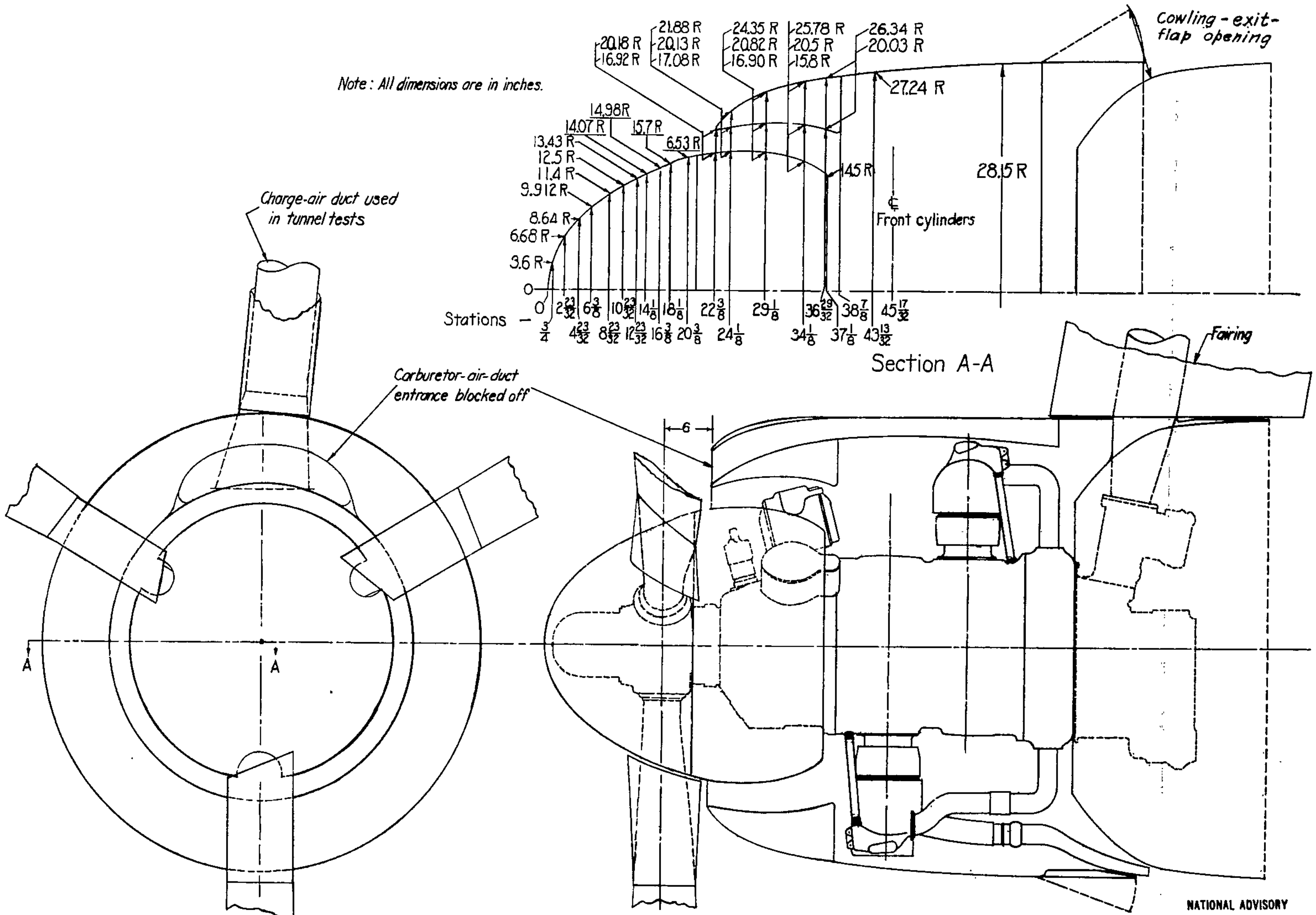


Figure 1.- Model on which the three spinner-diffuser arrangements were tested mounted in the LMAL 16-foot high-speed tunnel.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

Figure 2.-Outline sketch, original spinner-diffuser arrangement.

1041 J

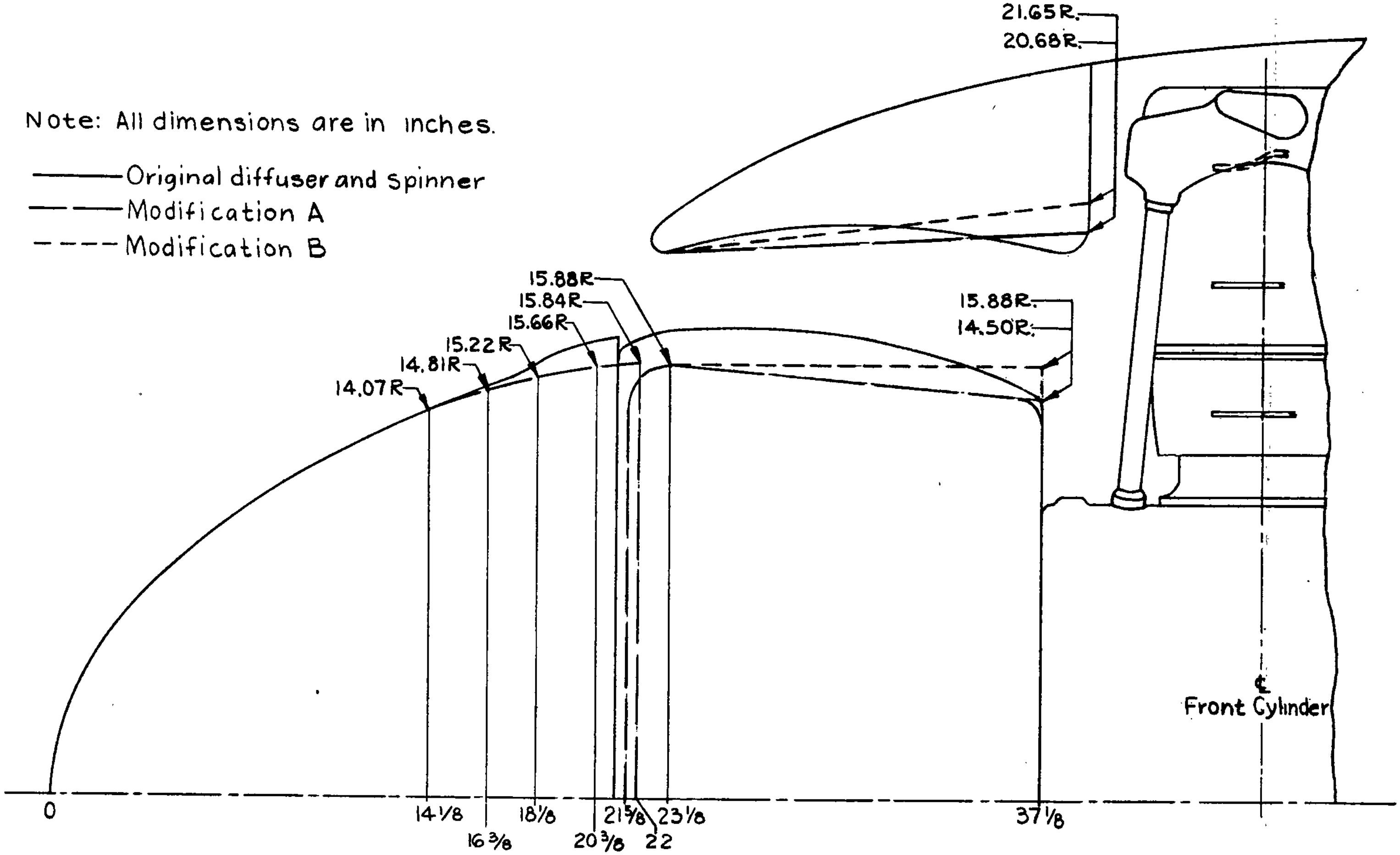


Figure 3. - Modifications to original diffuser and spinner.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

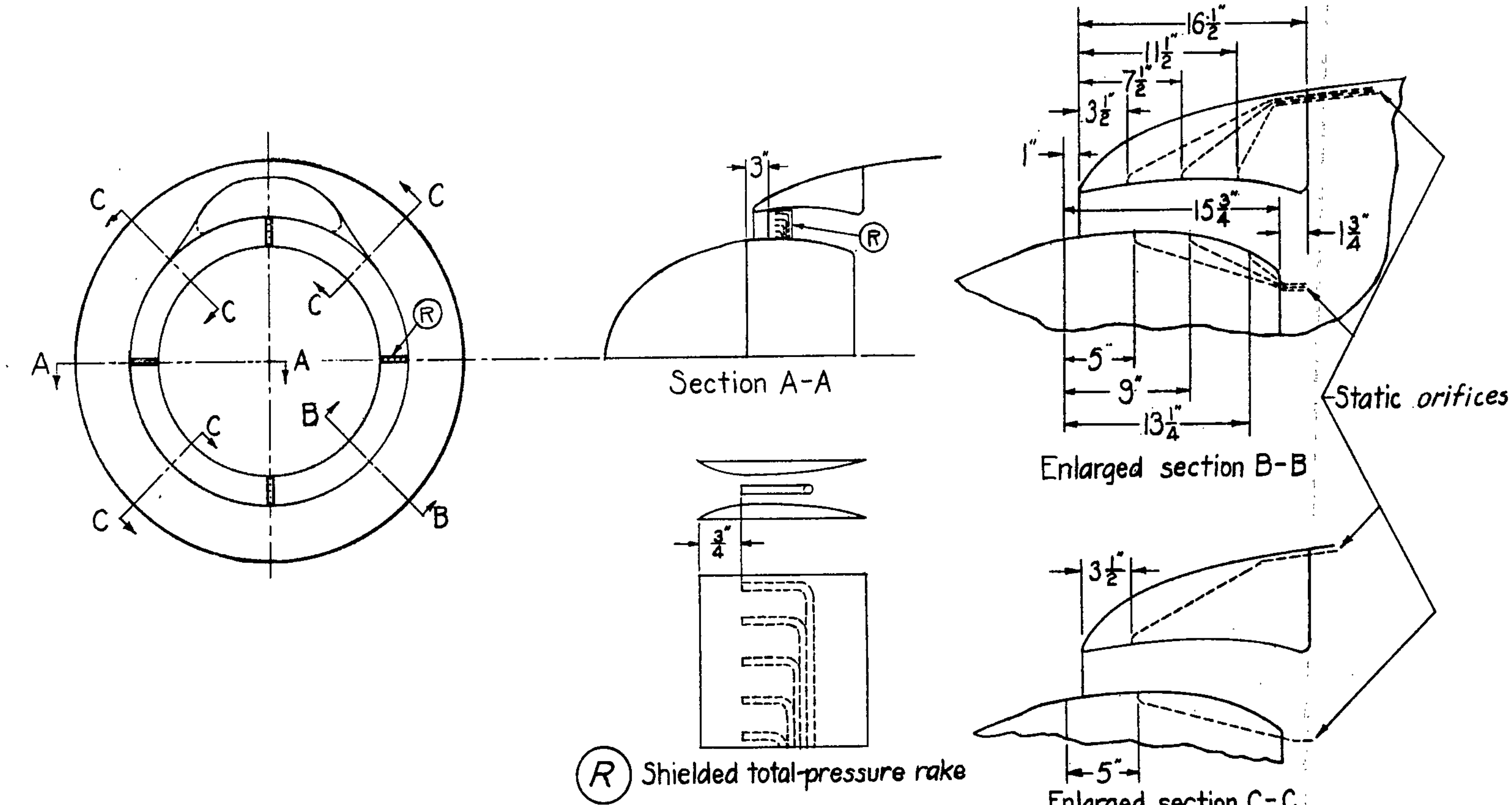


Figure 4.- Pressure-tube locations in original diffuser

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

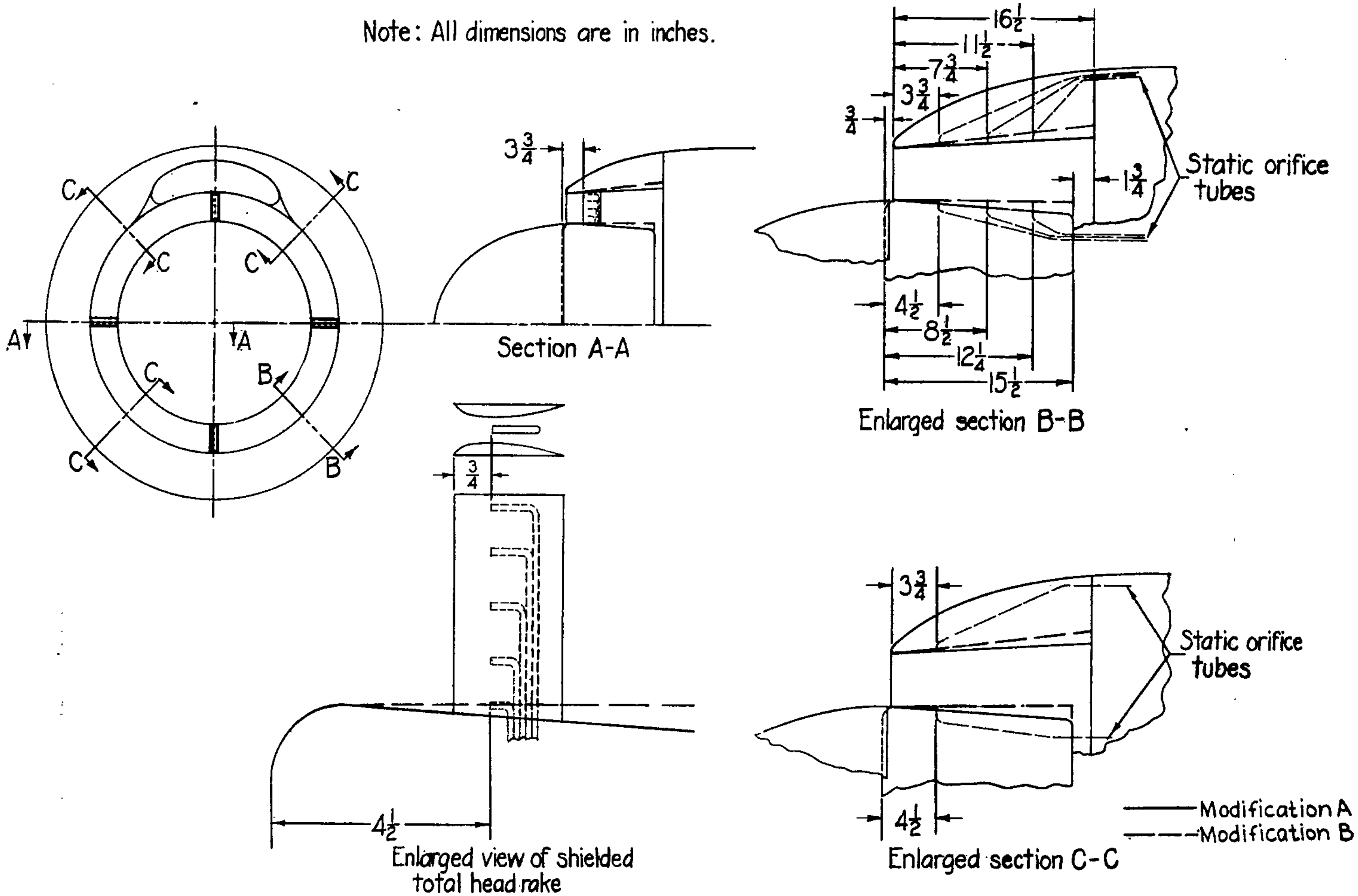


Figure 5.– Pressure-tube locations in modified diffusers.

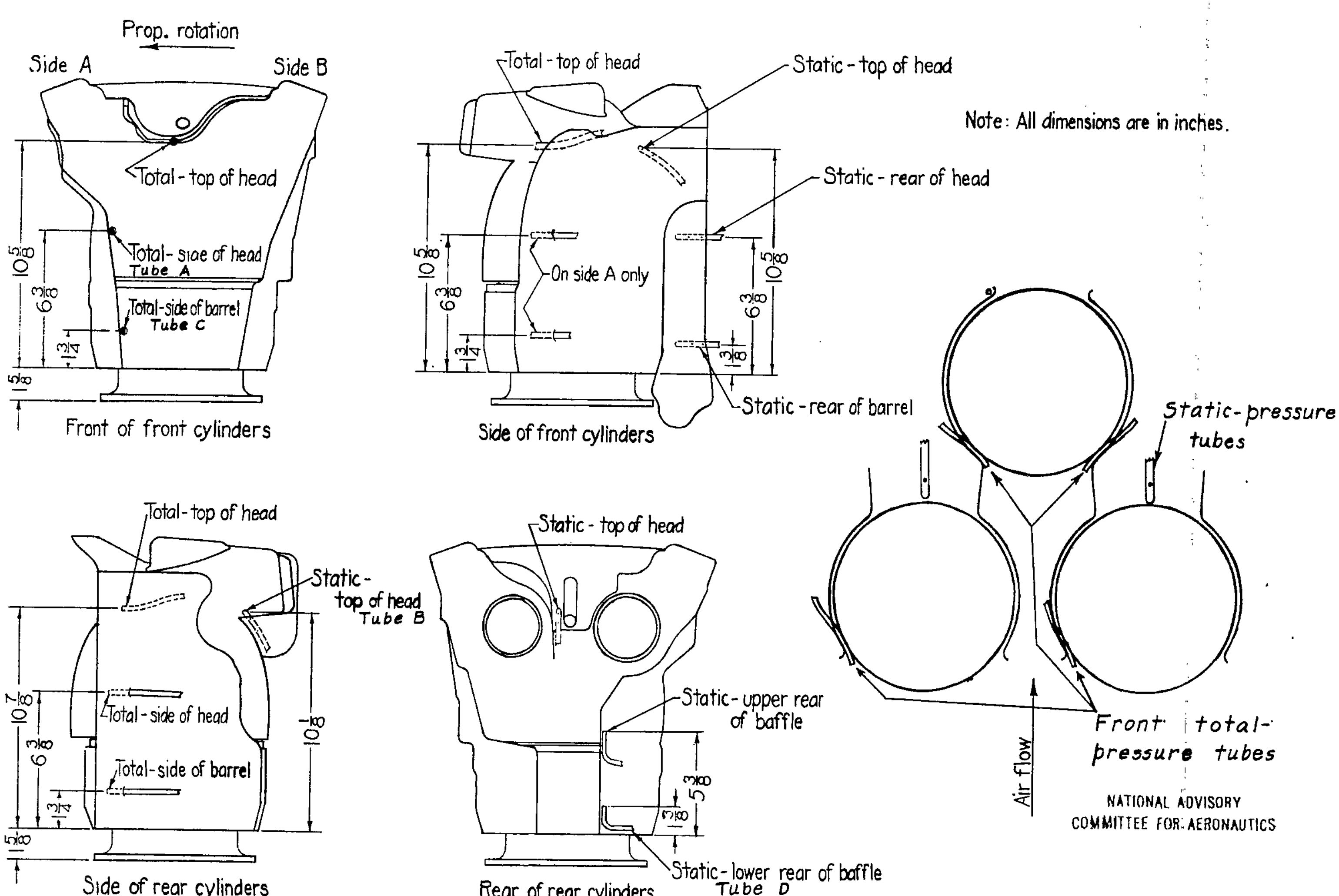


Figure 6.- Cylinder pressure-tube locations.

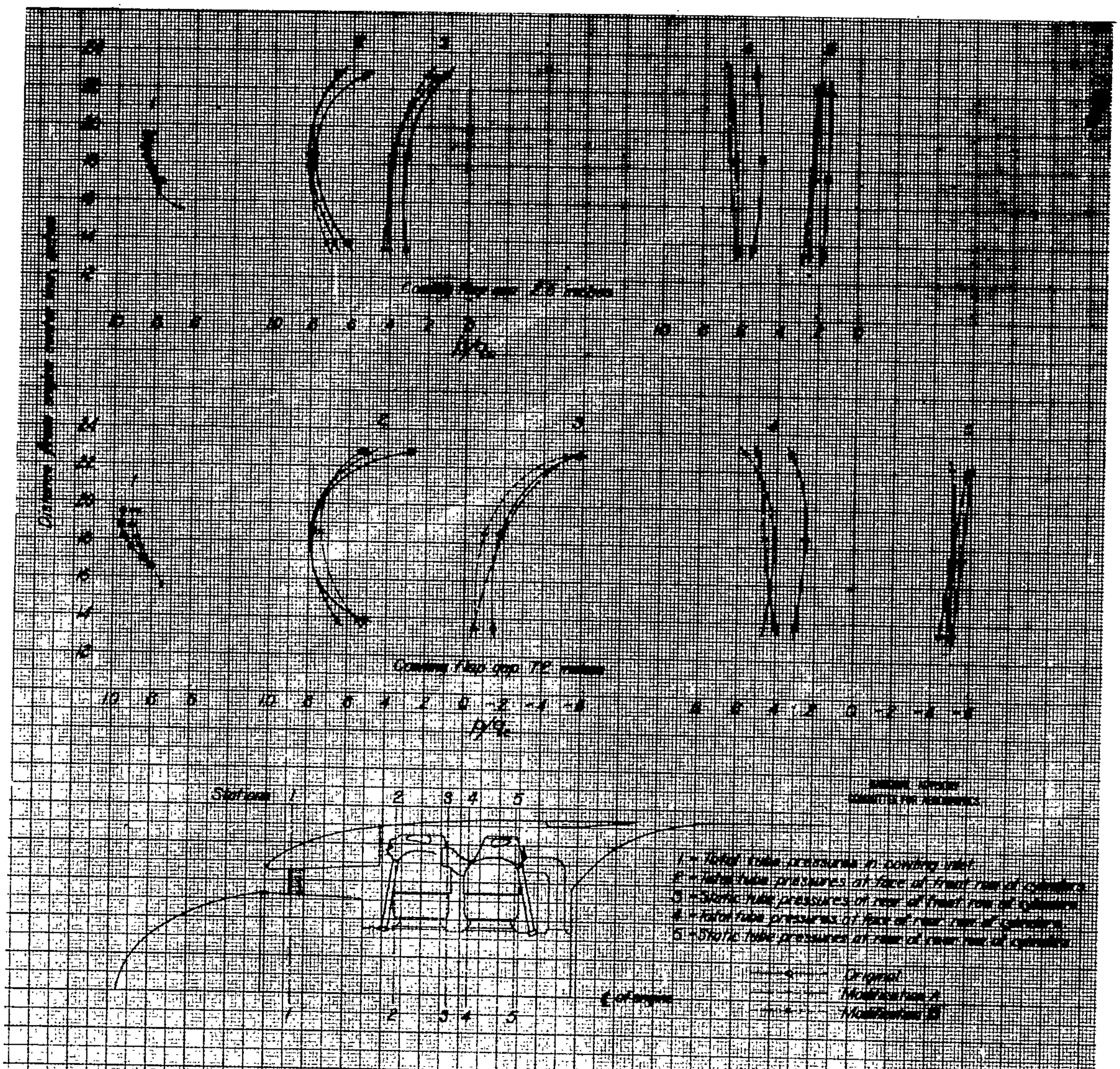


Figure 7.- Typical radial pressure gradients at various stations through the three spinner-diffuser arrangements for two cowling-flap gaps; $\alpha_T = 0°$, V=260mph, V/nD=1.7, C_P=.16, Test q_c=180 lb/sq ft.

1041 6

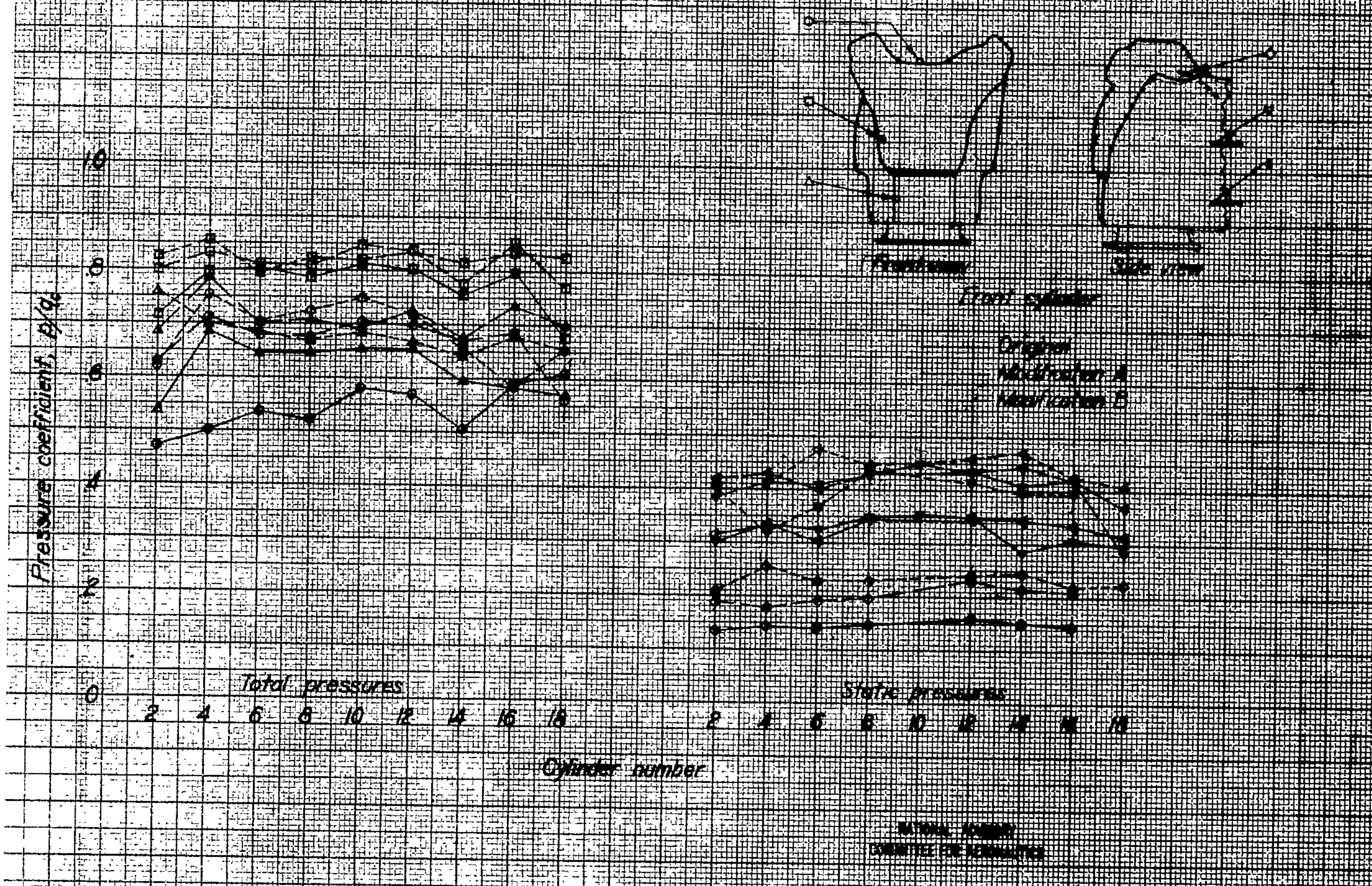


Figure 8.- Comparison of circumferential pressure distributions on the front bank of cylinders for the three spinner-diffuser arrangements; cowling-flap gap, 2.5 in.; V, 260 mph; V/nD, 1.7; C_p, 0.16; test q_c, 180 lb/sq ft; pair 6.

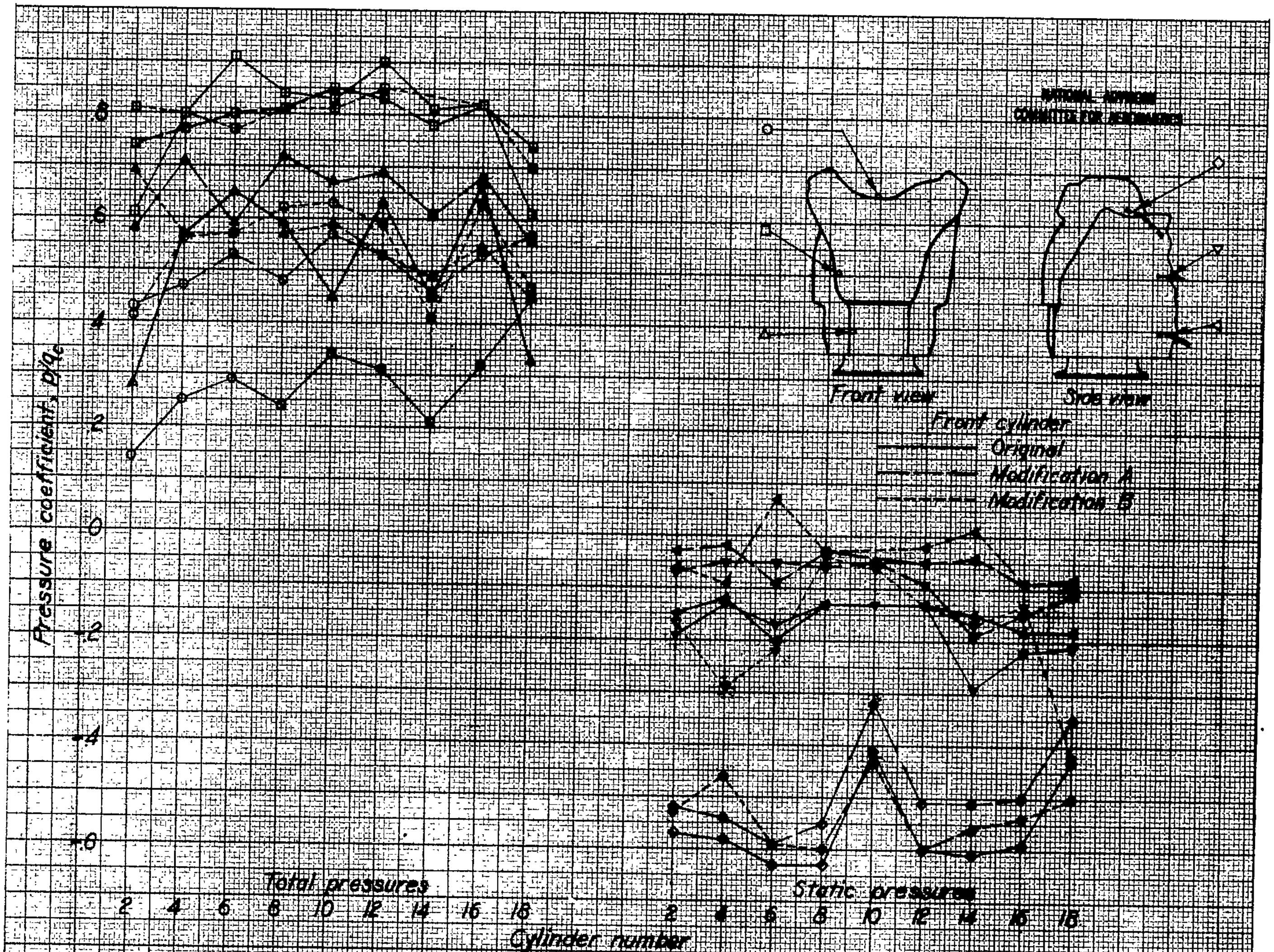


Figure 9.- Comparison of circumferential pressure distributions on the front bank of cylinders for the three spinner-diffuser arrangements; cowling-flap gap, 7.2 in.; V, 260 mph; V/nD, 1.7; C_p, 0.16; test q_c, 180 lb/sq ft; α_T, 0°.

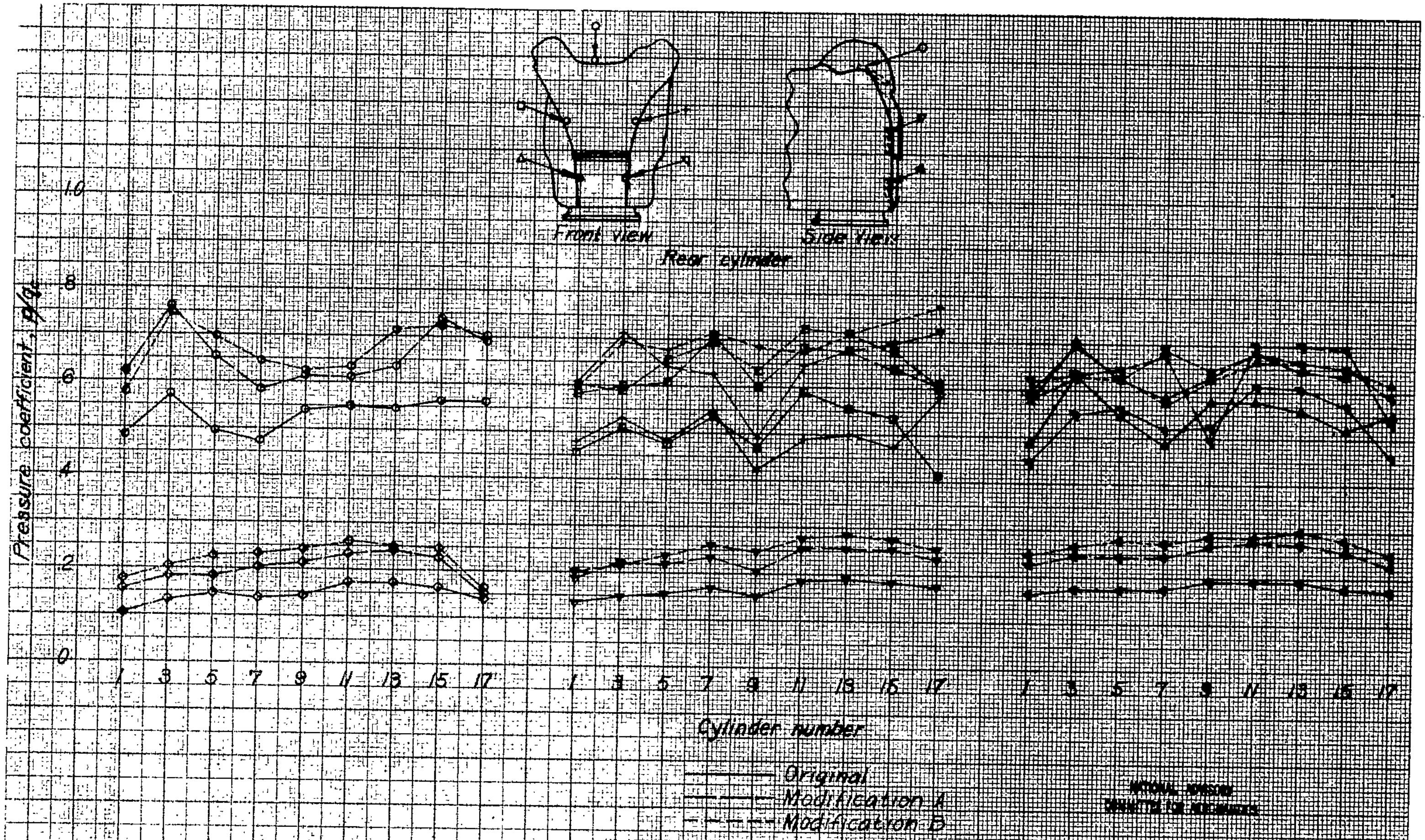


Figure 10.- Comparison of circumferential pressure distributions on the rear bank of cylinders for the three spinner-diffuser arrangements. Cowling-flap gap, 2.5 in.; V, 260 mph; V/nD, 1.7; C_p, 0.16; test q_c, 180 lb/sq ft; α_T, -0.5°.

104111

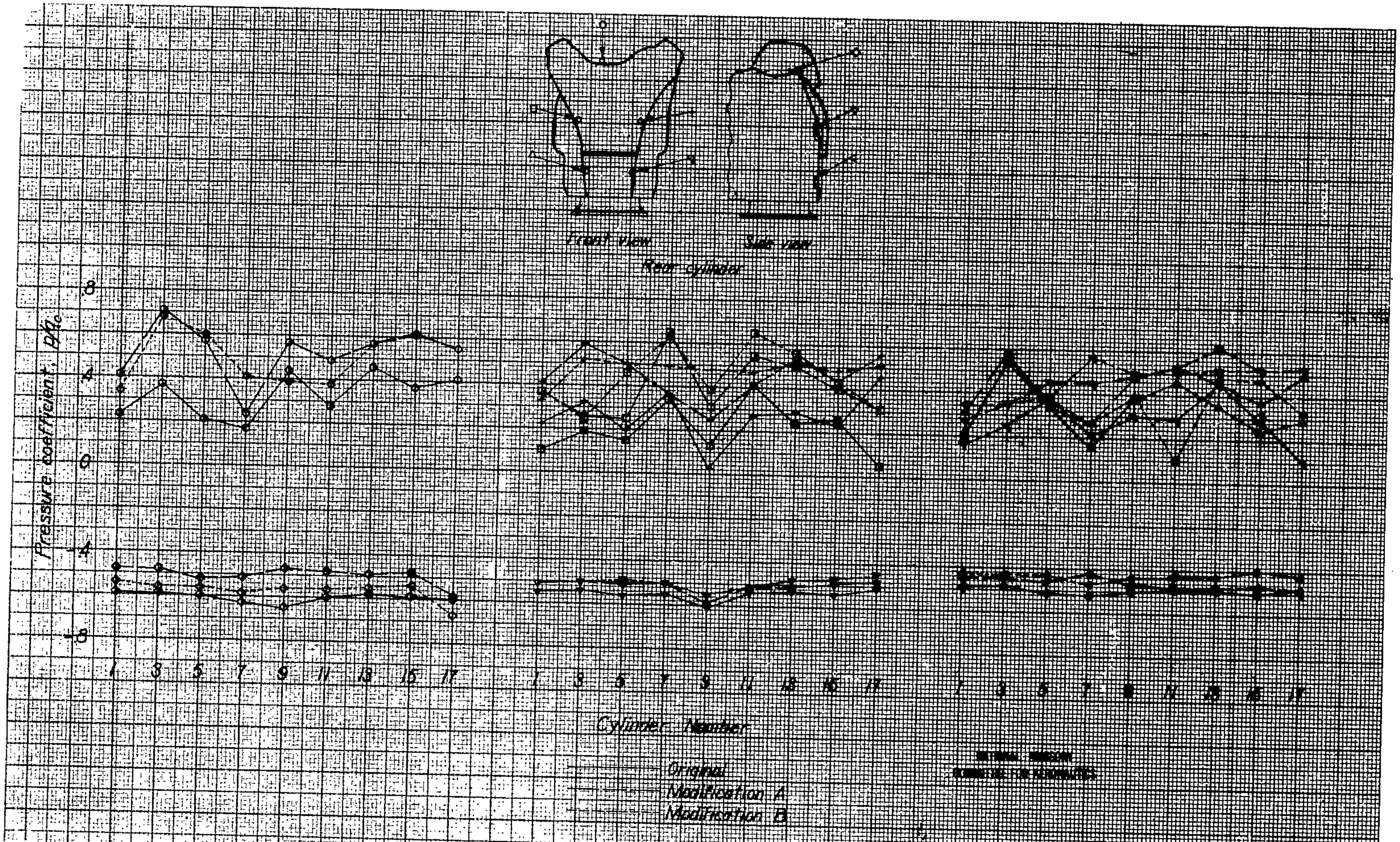


Figure 11.- Comparison of circumferential pressure distribution on rear bank of cylinders for the three spinner-diffuser arrangements; cowling flap gap, 7.2 in.; V, 260 mph; V/nD, 1.7; C_p, 0.16; test q_c, 180 lb/sq ft; α_T, 0°.

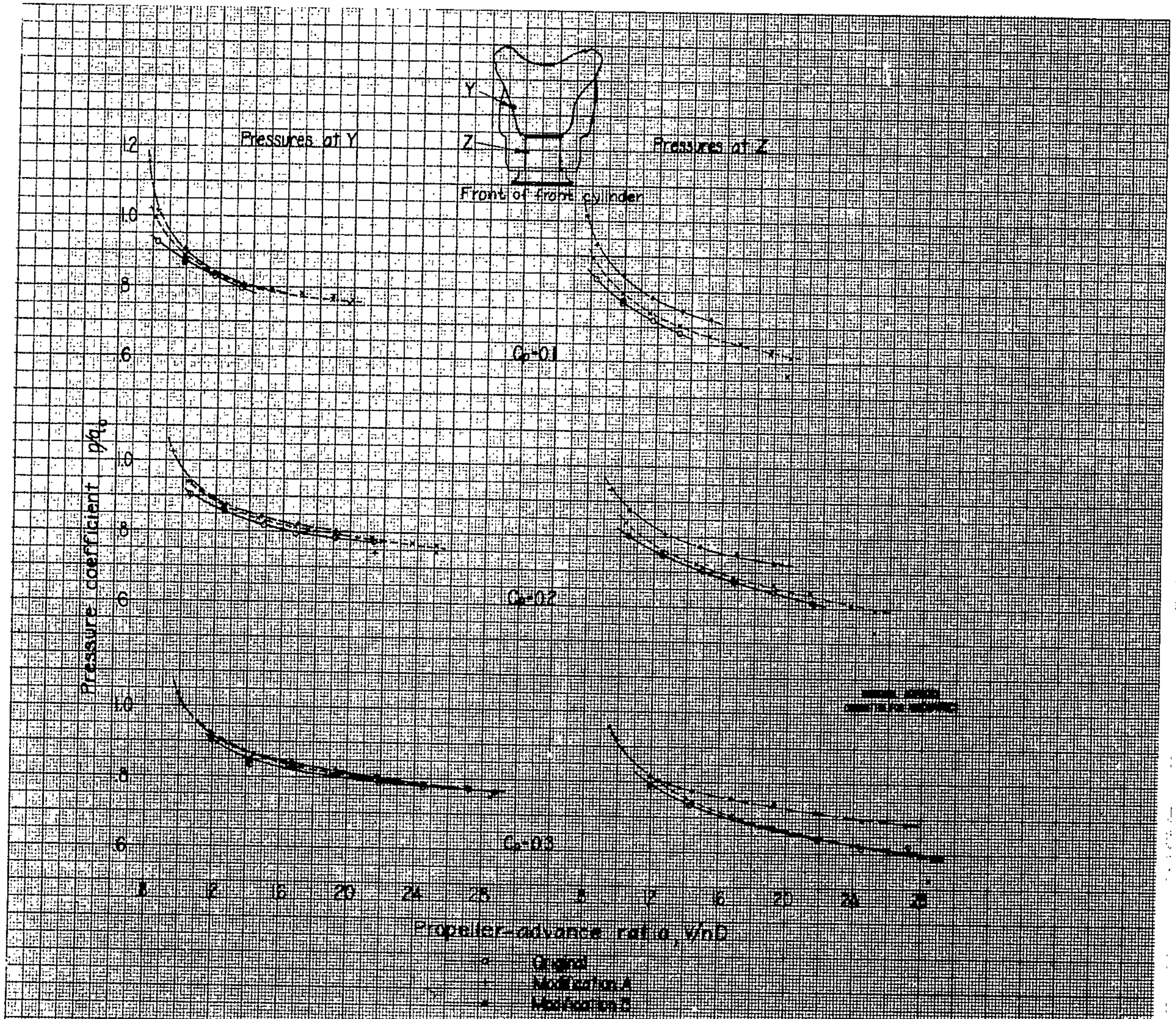


Figure 12. - Variation of pressure available at the face of the engine with propeller advance ratio, cowling-flap gap, 2.5 inches; 0° angle of attack.

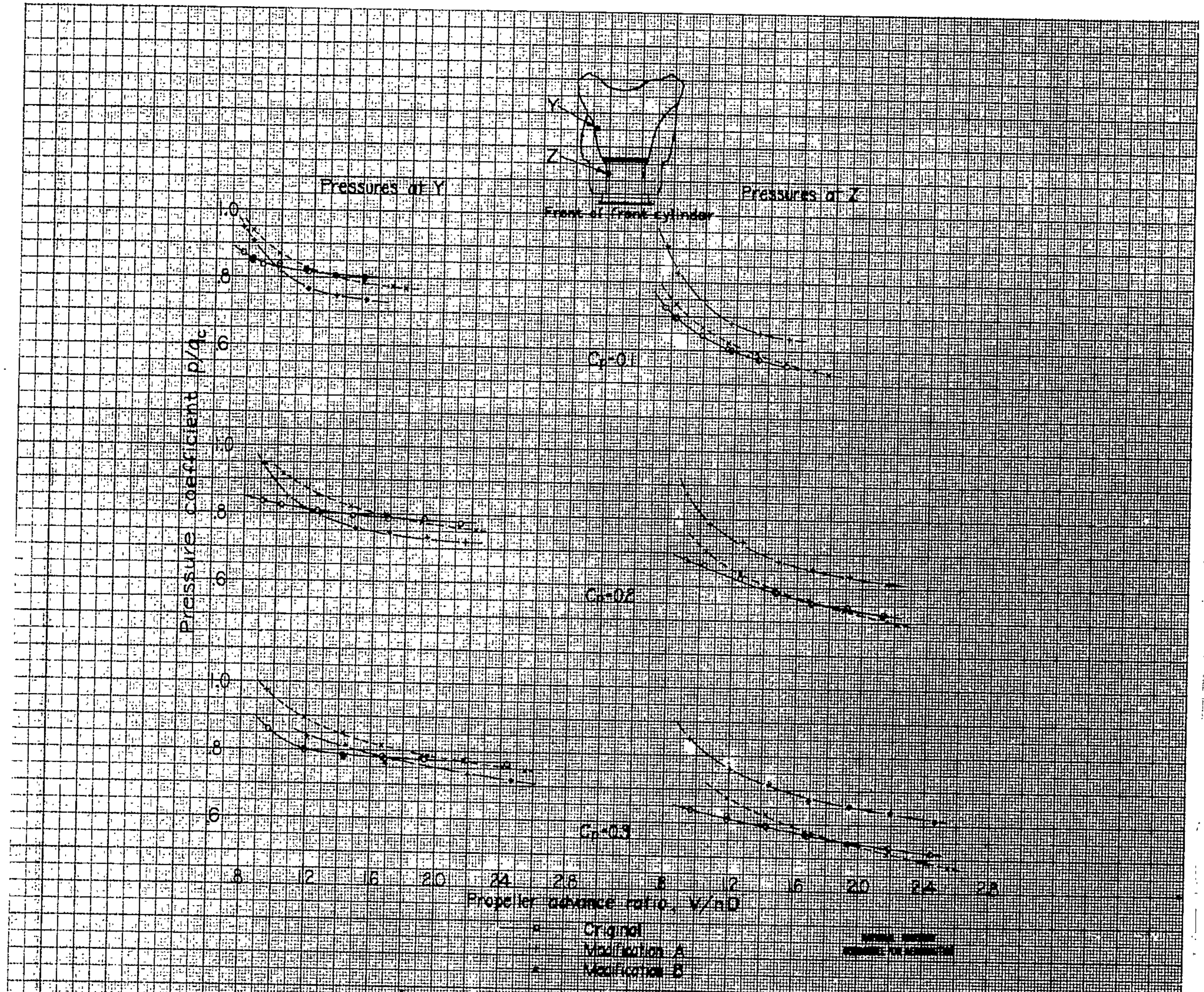


Figure 13.- Variation of pressure available at face of the engine with propeller advance ratio; cowling flap gap, 7.2 inches; 0° angle of attack.

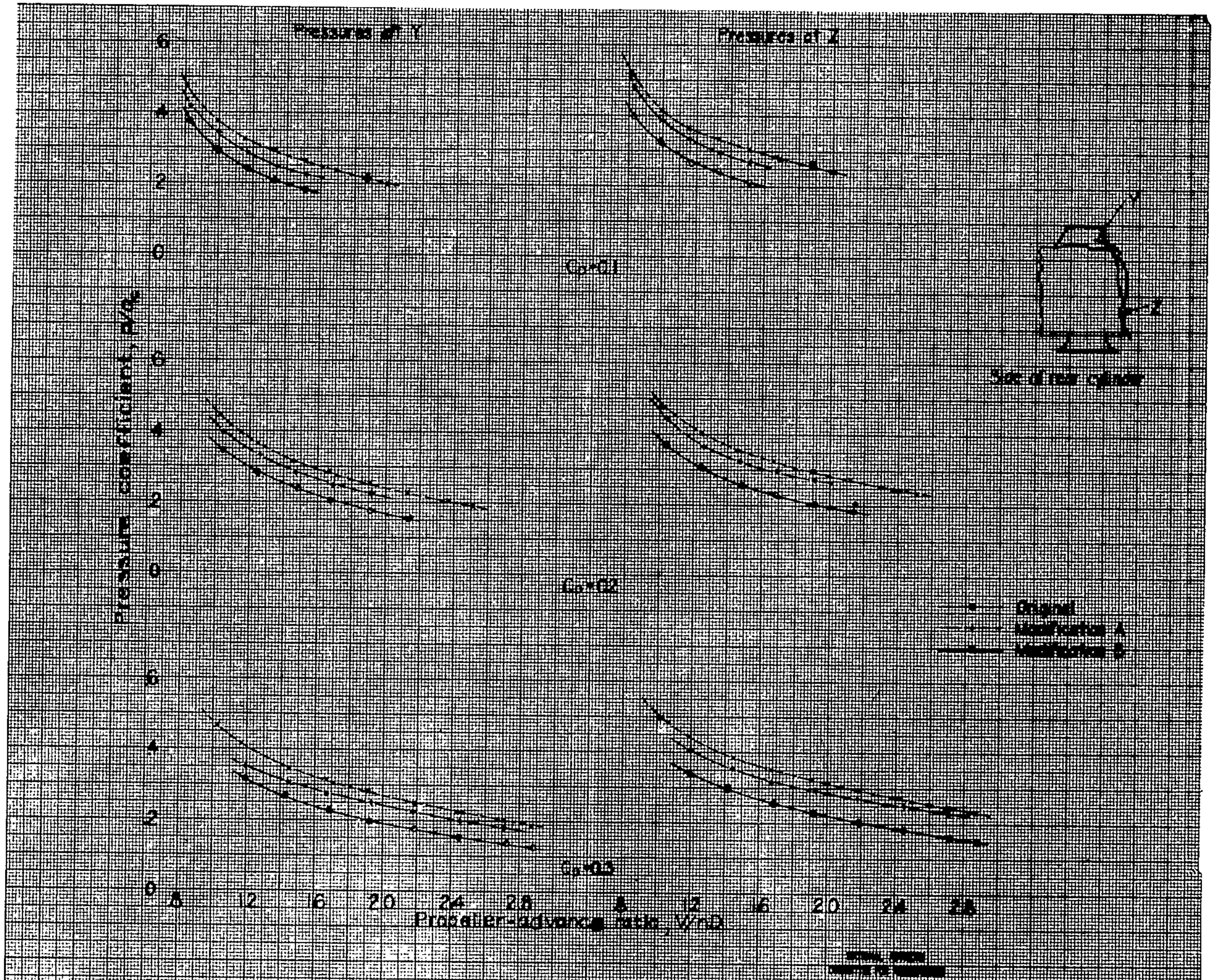


Figure 14 - Variation of static pressure at rear of engine with propeller-advance ratio. Cowling-flap gap 2.5 inches. 0° angle of attack.

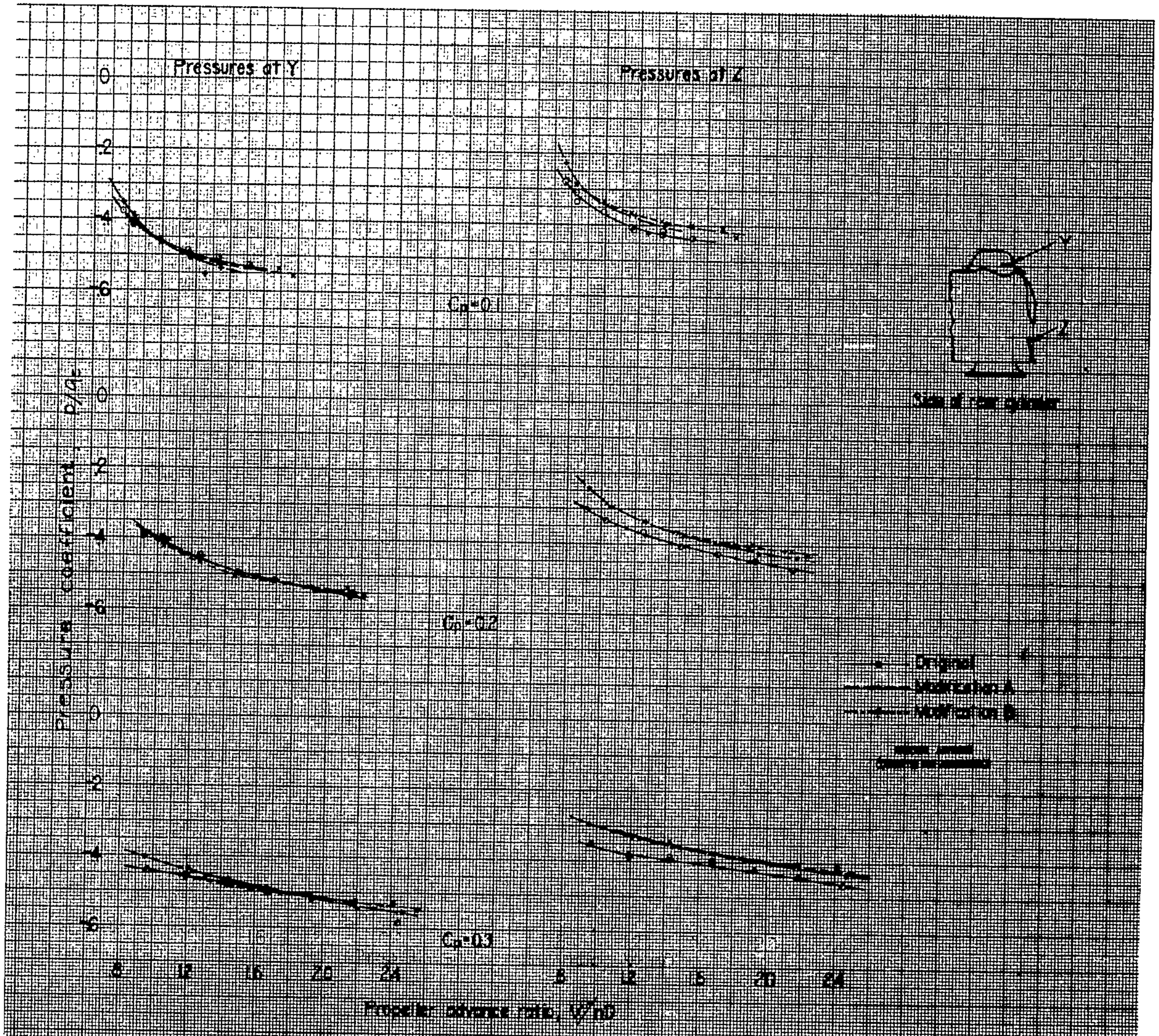


Figure 15. Variation of static pressure at rear of engine with propeller ratio, cowling flap gap, [illegible] inches, 0° angle of attack.

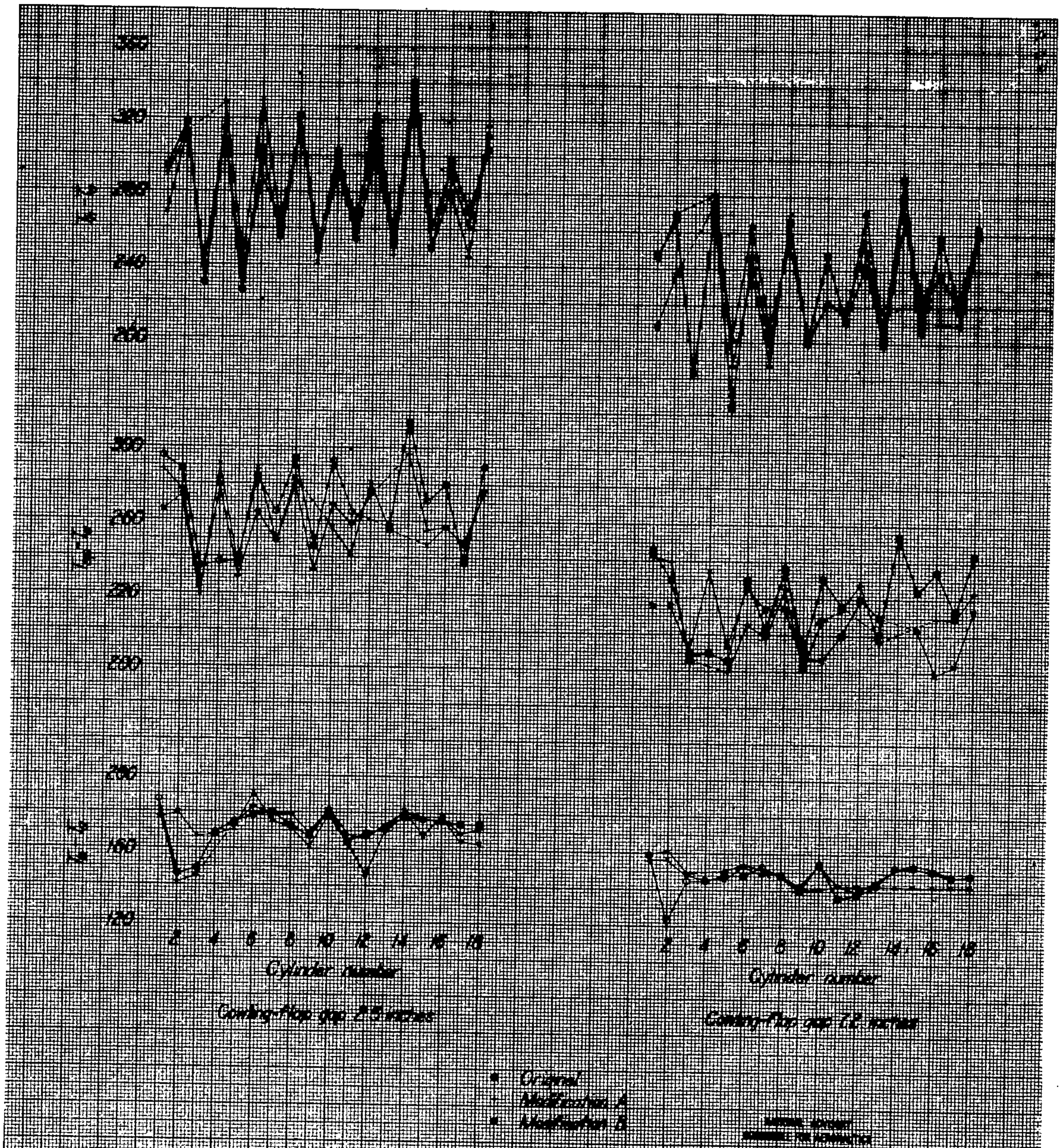


Figure 16.- Typical temperature patterns for the three spinner-diffuser arrangements; α, 0°; 1100 bhp; 2120 rpm; f/A, 0.08; V, 260 mph.

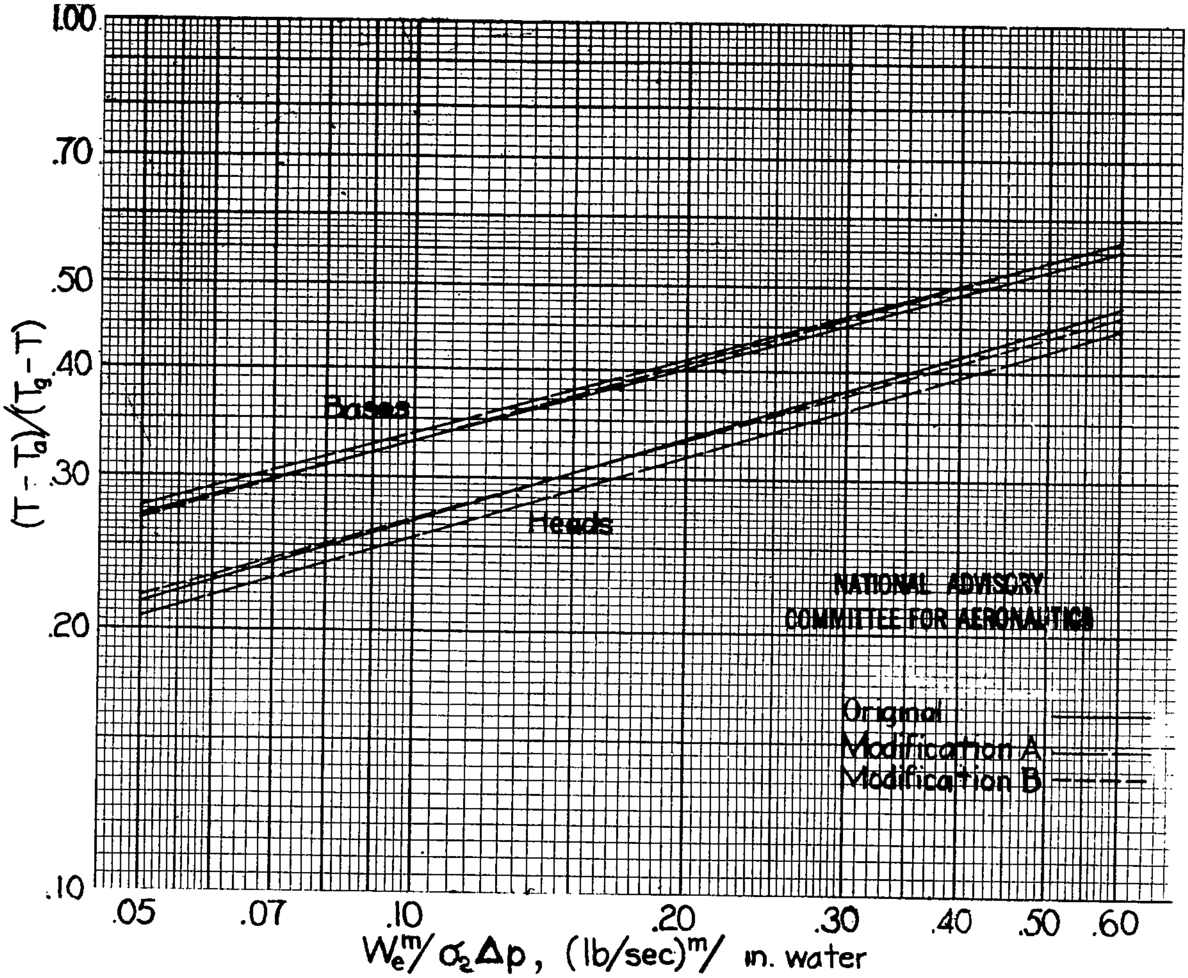


Figure 17.– Comparison of engine-cooling correlations for the three spinner-diffuser arrangements.

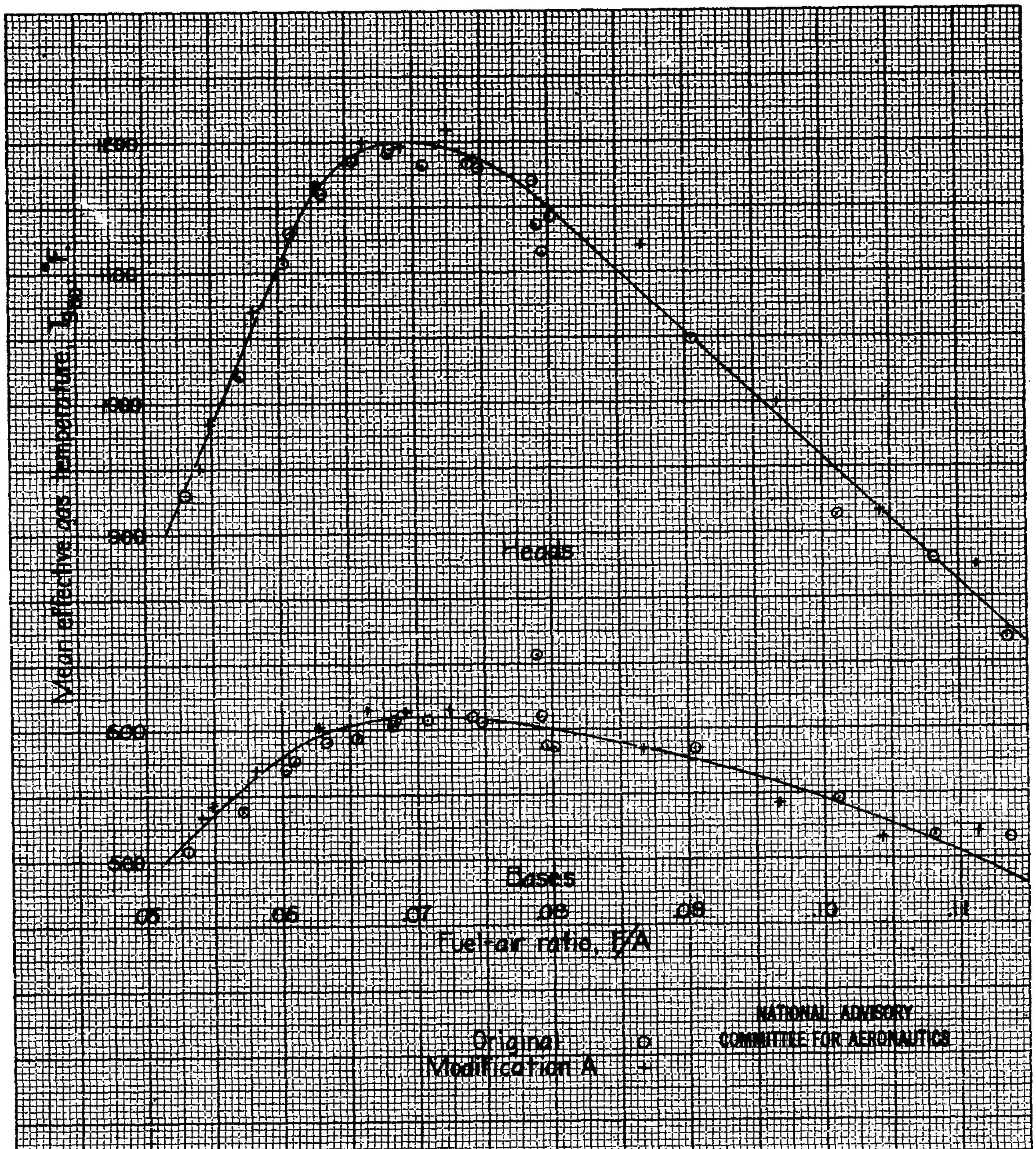
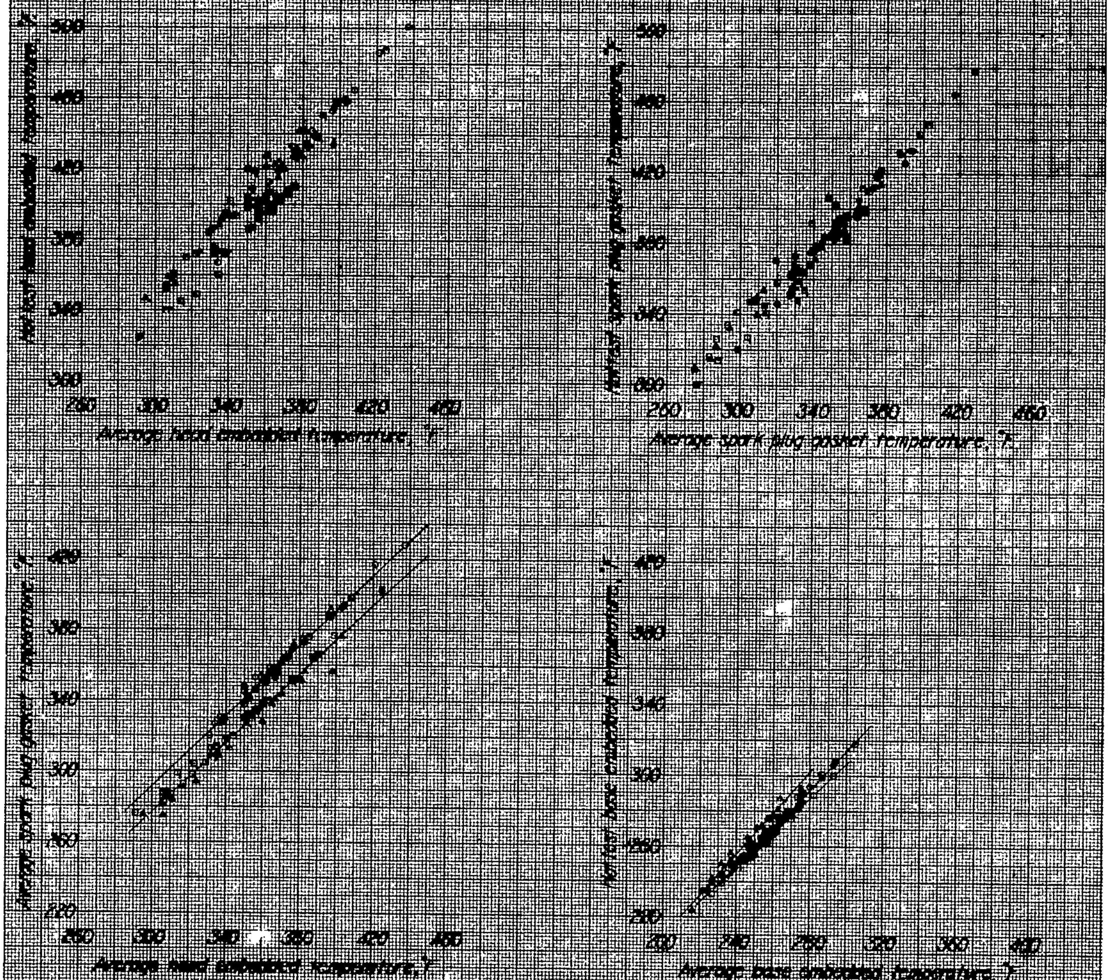


Figure 18. - Variation of mean effective gas temperature with fuel-air ratio.



Spinner-diffuser Arrangement	Variable $c_p\Delta p$	W_c	F/A
Original	●	●	●
Modification A	■	■	■
Modification B	▲	▲	

Figure 19.- Engine temperature relationships for the large spinner-diffuser arrangements.

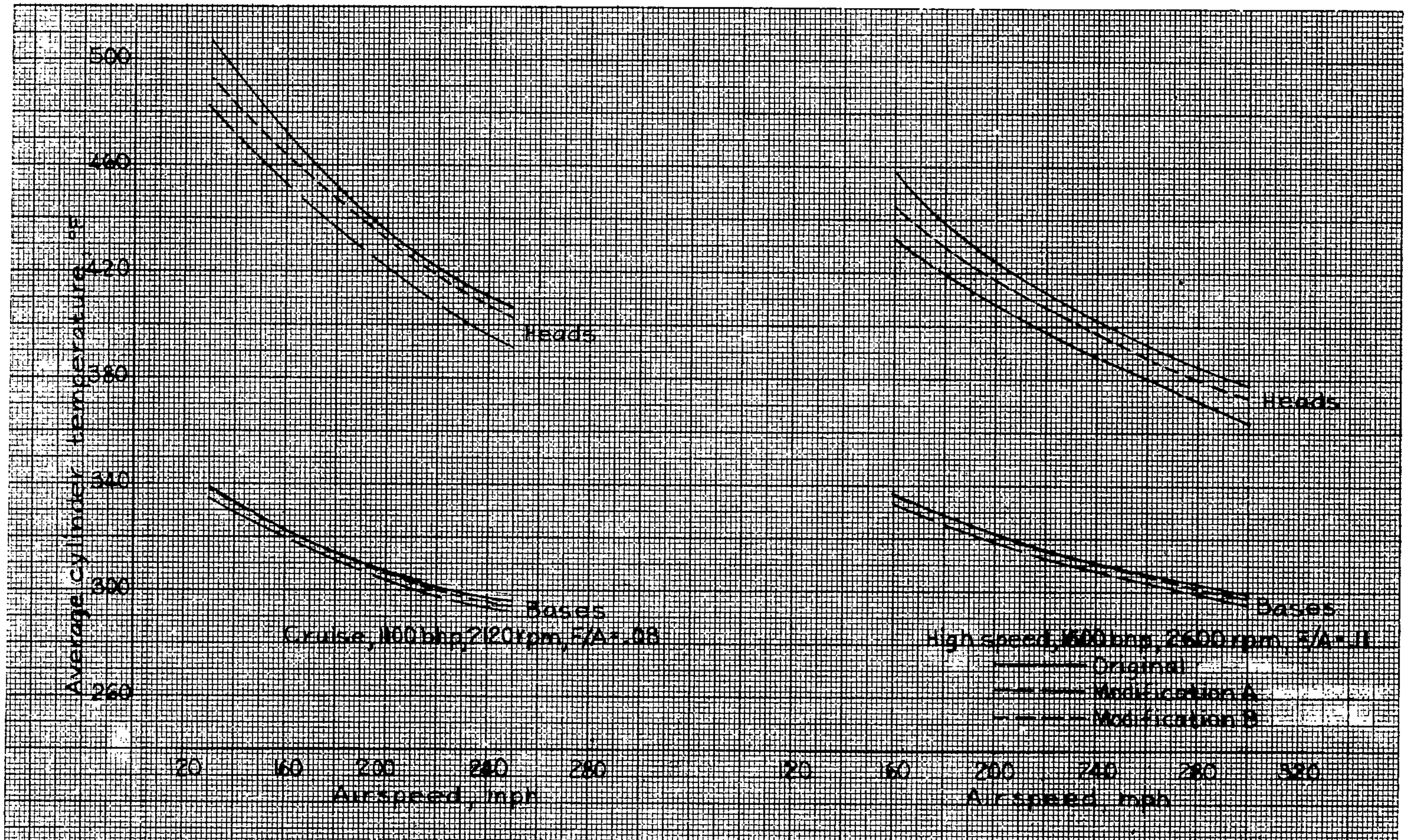


Figure 20.- Variation of cylinder temperature with airspeed at sea level. Free-air temperature, 100°F; cowling-flap gap, 2.5 in.